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2021 Robotics Handbook

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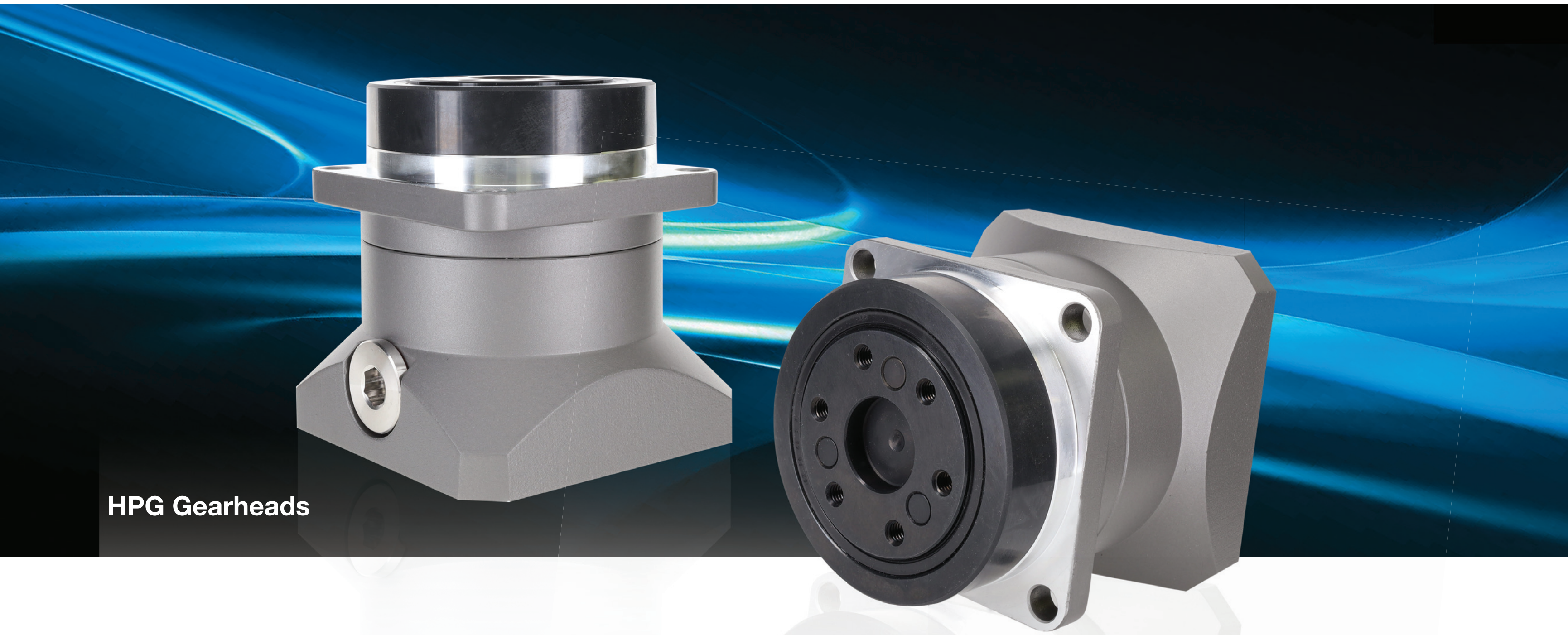

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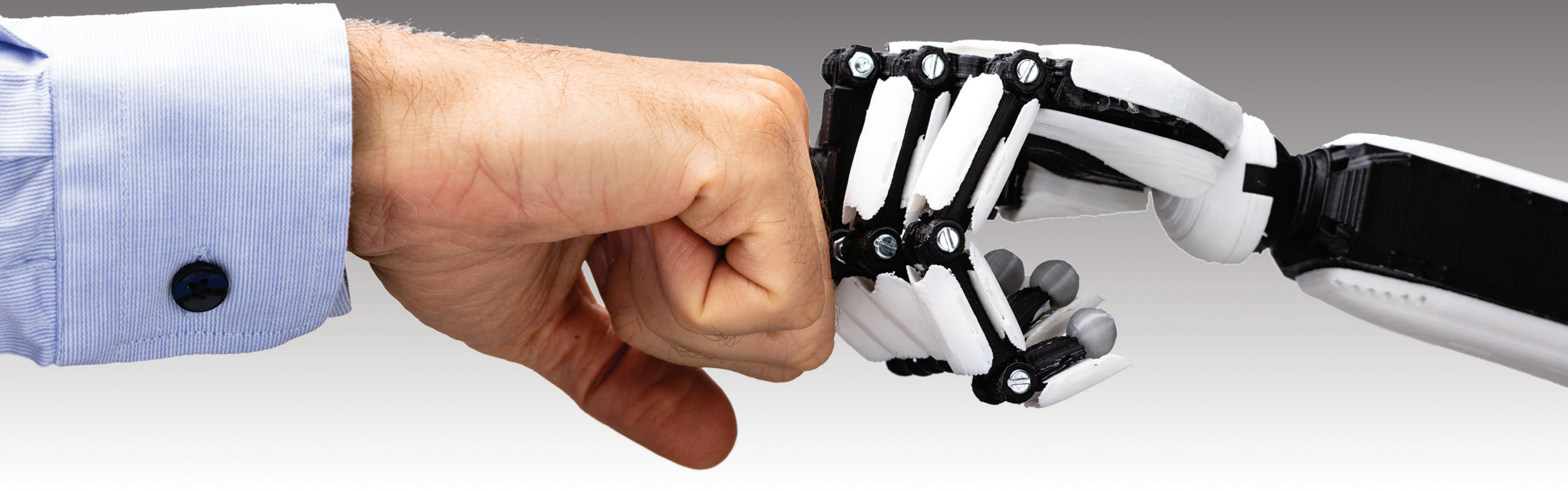

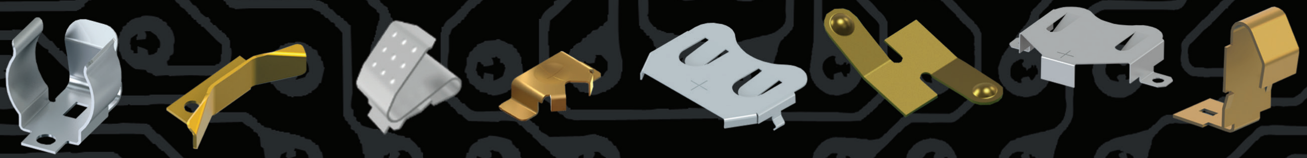

ROBOTS, AUTOMATION & THEIR ELECTRONICS

Featuring Battery Clips, Contacts & Retainers

Though robots and automation are in use today in a wide variety of industries, robotics is still considered a futuristic idea. Many may be surprised to learn that the first electronic robots were built in 1948. What's even more surprising is evidence of the first automaton taking us back 800 years and writings from Turkey indicating automatic devices used to entertain.

Entertainment was the main drive behind the development of automatons for many centuries. Eventually, the benefits of automating simple, repetitive functions reached the manufacturing sector and grew into the complex, computer-driven automation we know today.

Advances in computers and electronics have facilitated fast progress for industrial automation. Factories and other industrial operations use robots for a wide range of automated processes.

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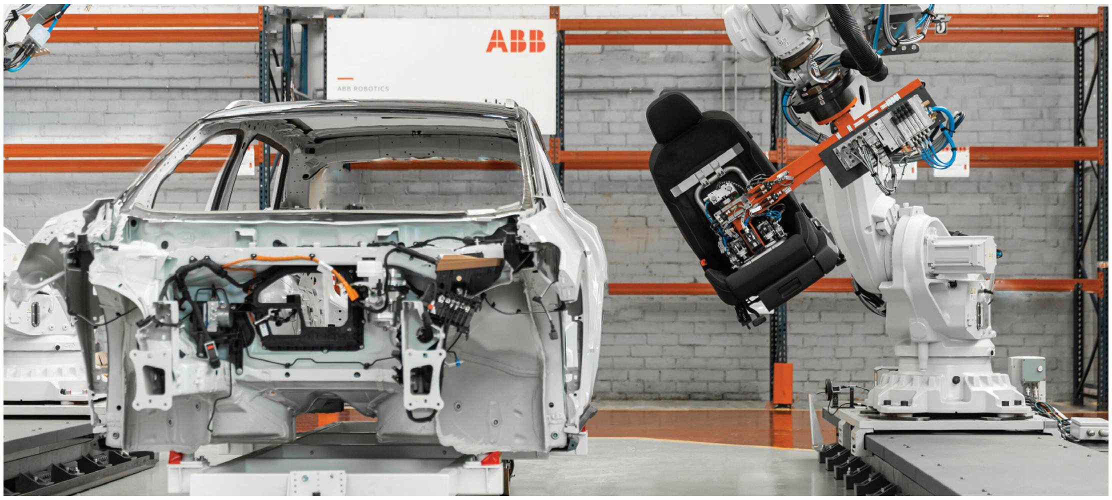

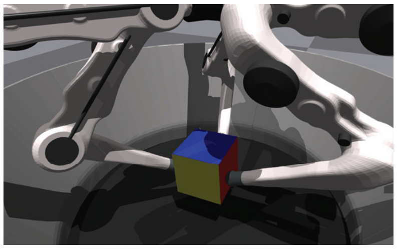

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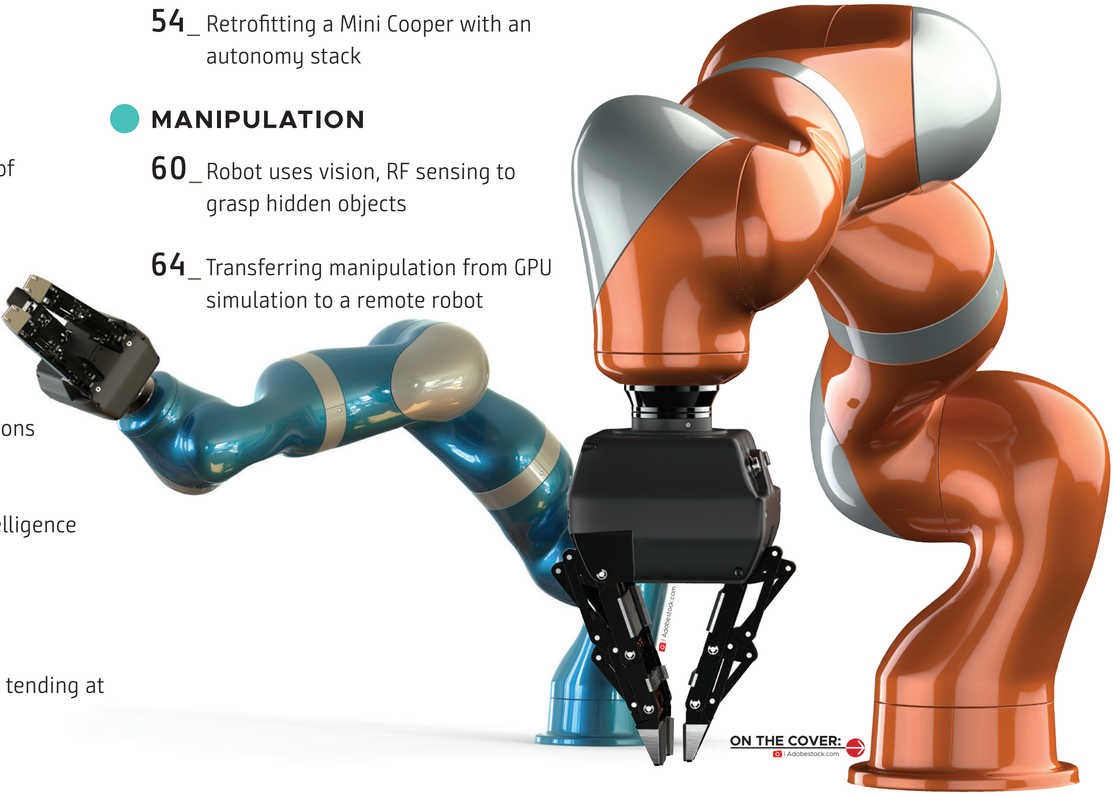

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Editor's Note

Amazon underwhelms with Astro

There have already been several failed attempts at multipurpose home robots. Amazon's consumer robot will likely suffer the same fate.

Steve Crowe | Editorial Director, *The Robot Report*

The rumors were true. Amazon has been working on a home robot for years. And Ryan Hickman, who founded the cloud robotics team at Google in 2010, couldn't have been more spot on with his prediction.

Amazon finally unveiled Astro, which is essentially an Echo Show 10 on wheels. In 2018, Hickman offered up his reasons for why an Alexa on wheels made the most sense. Apparently Amazon agreed.

Amazon said Astro can be used for a variety of things, including home monitoring, video conferencing with family and friends, entertaining children, and all of the same features we've come to know and love from Alexa devices – listening to music, checking your schedule, etc. Astro can map your home and go to specific rooms on command. The voice-controllable robot can recognize faces, deliver items to specific people, after a human puts the item in the storage bin, and use third-party accessories to, for example, record blood pressure. It can detect the sound of a smoke alarm, carbon monoxide detector or breaking glass. If you have a Ring account, Astro can send you notifications if it notices something unusual.

Astro is two feet tall and weighs 20 lb. Its main drive wheels are about 12 inches in diameter, and Astro's top speed is 3.3 feet per second. The screen is similar to

Astro is two feet tall and weighs 20 lb. *Its main drive wheels are about 12 inches in diameter, and Astro's top speed is 3.3 feet per second.*

📷 | *Amazon*

that of an Echo Show 10, and the robot uses a 5-megapixel video calling camera.

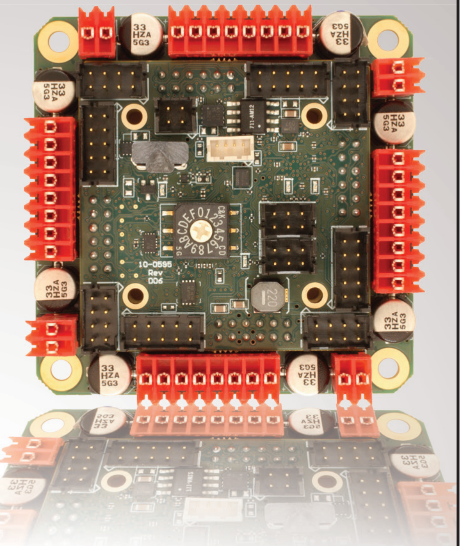
Later this year, Amazon will sell a limited number of Astros. After an introductory price of $999.99, Astro's price will increase to $1,449.99.

Been there, done that

Haven't we been down this road already? We've seen several multipurpose home robots crash and burn over the years. Anki, Blue Frog Robotics, Jibo, and Mayfield Robotics are a few that immediately come to mind. These companies suffered from a number of issues, but the main challenges were pricing, performance, and funding.

While access to financial support shouldn't be a problem for Astro, cost-performance and privacy very well could be. It can't go up and down stairs. It doesn't have arms to pick up and transport items. It has limited storage capacity. It can't go outside. It won't deter an intruder who's already in a house. And its functionality is limited for users who don't subscribe to other Amazon smart home products such as Ring.

As I've said before, that's a lot of money for consumers to pay to be able to check the weather, play your favorite tunes, or FaceTime with grandma. Amazon has sold millions of Echo devices at much cheaper prices. At press time,



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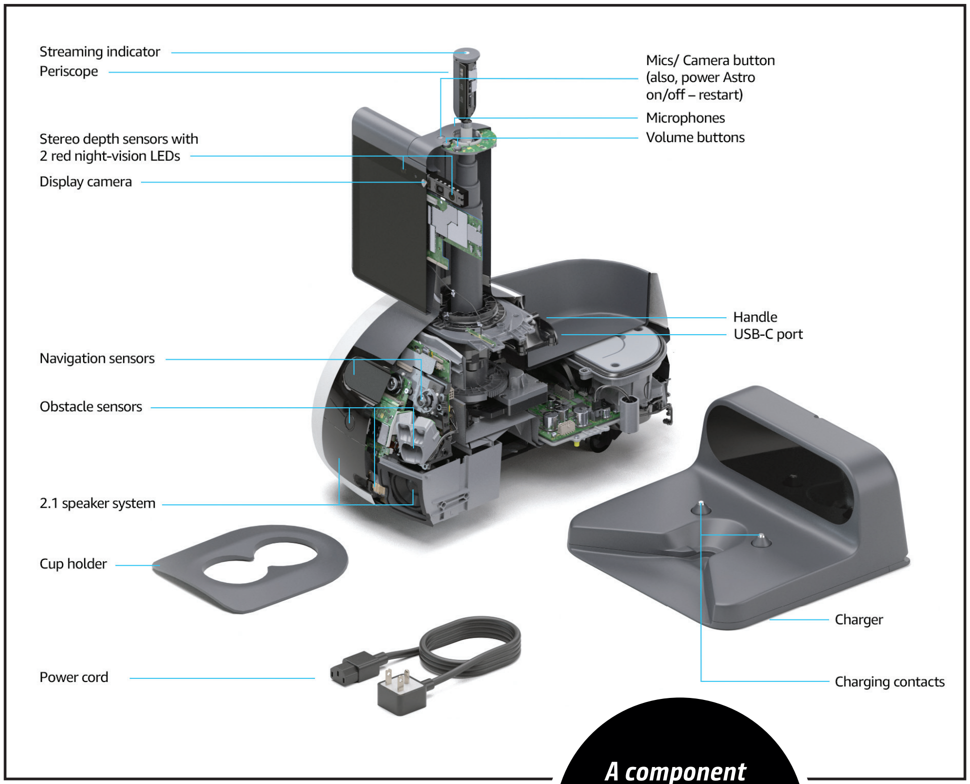
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***A component breakdown** of Amazon Astro.*

| Amazon

an Echo Show 5 can be purchased for just $45. Sure, it doesn't have all the latest bells and whistles, but I could buy 32 Echo 5s and place them throughout my home for the same price as 1 Astro robot.

Amazon said it is keeping privacy in mind with Astro. Users can turn off mics, cameras, and motion with one press of a button and set "out of bounds zones" to keep the robot out of certain rooms. Of course, Amazon has said this for other products in the past, but privacy issues persist.

The engineering and overall product development from Amazon should be better than the aforementioned consumer robots. And Astro has access to a vast network of Amazon-related content and smart home devices that could turn it into a smart home controller for certain users, too. This was a major problem for Buddy, Cozmo, Jibo, and Kuri.

But will that be enough? The most successful consumer robot to date remains a single-purpose home robot: the Roomba. Multipurpose home robots have never been able to crack the code. I hope I'm wrong, but Astro's likely to have the same fate. Despite spending many years, and likely a ridiculous amount of money, Amazon is limiting the sales of Astro. So it doesn't seem too confident in Astro's future either. **RR**

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THE ROBOT REPORT

EXPLORING THE BUSINESS AND APPLICATIONS OF ROBOTICS

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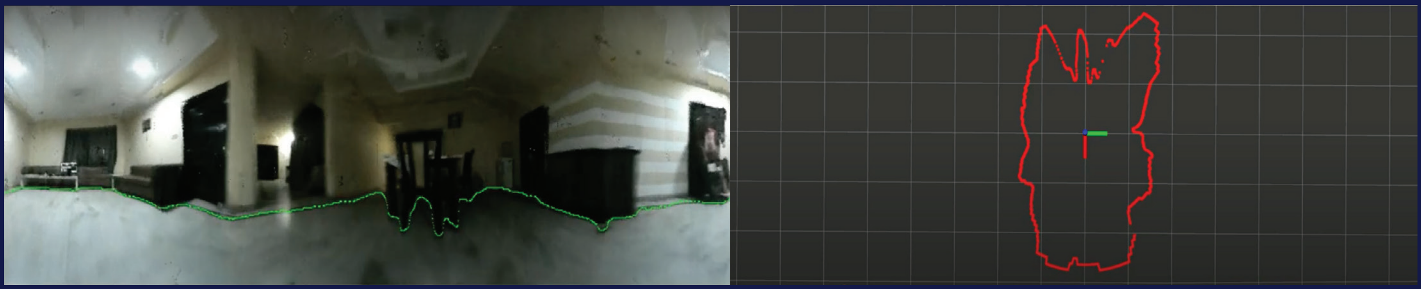
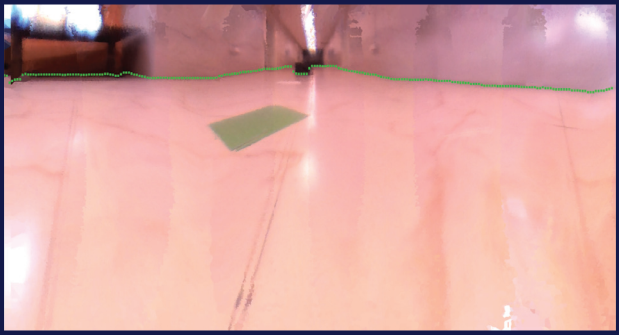


Simulated 2D laser scan output overlaid on 360° RGB with real-time 360° mapping output in ROS



Detect different types of obstacles with no false positives even on challenging floor types

Accurately detect floating obstacles in 3D even in varying lighting conditions

How ROS 2 is easing hardware acceleration for robotics

***The ROS 2 Hardware Acceleration Working Group** is creating acceleration kernels based on open standards.*

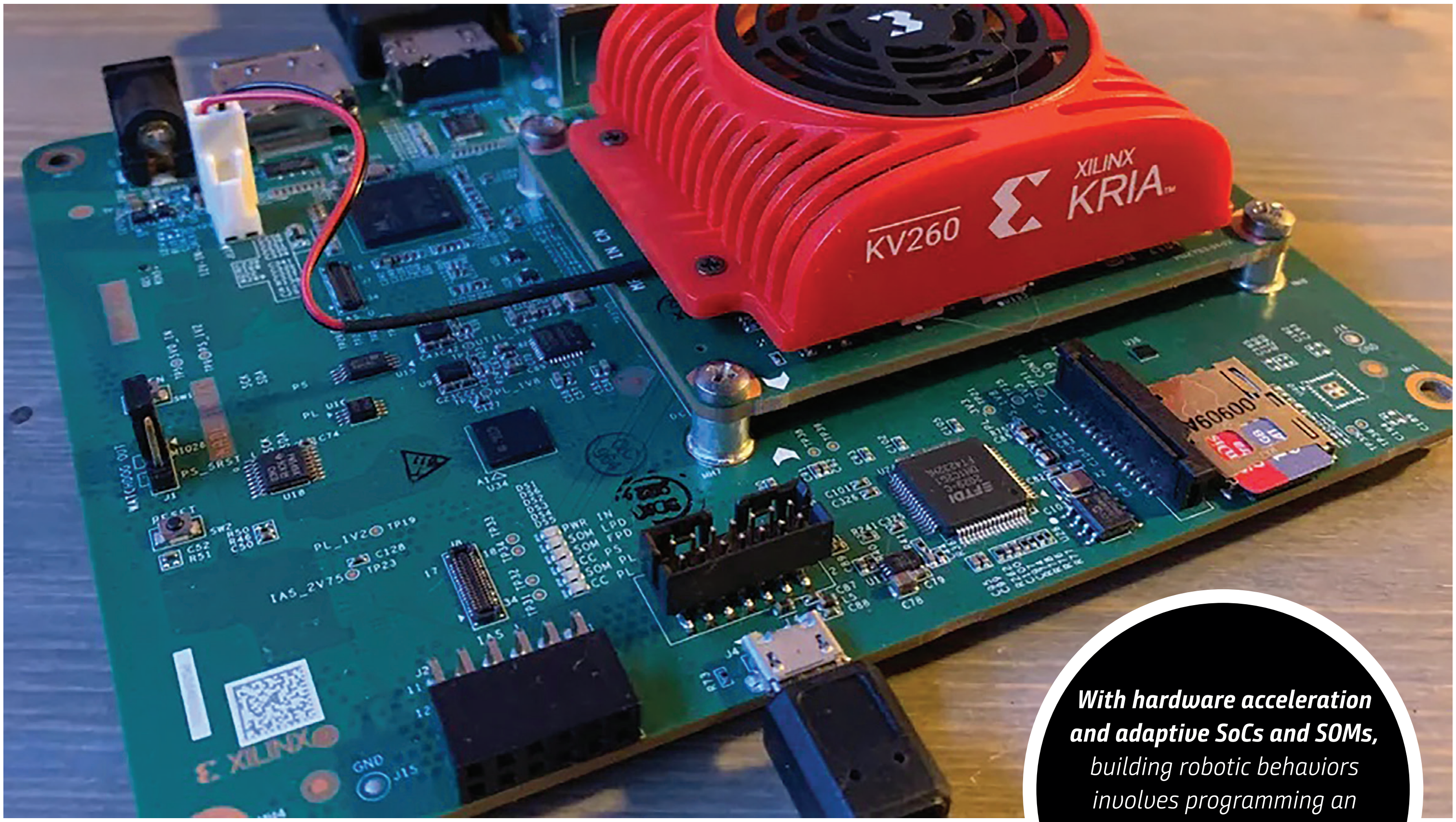
■ Victor Mayoral-Vilches • Xilinx

A robot is a network of networks. One that uses sensors to perceive the world, actuators to produce a physical change, and dedicated computational resources to process it all and respond to events in a coherent, timely manner. As such, robotics development is largely the art of system integration, both in terms of software and hardware, with a significant portion of robotics development resources dedicated to systems integration efforts.

With the wide availability of low cost, highly functional, collaborative robots, many companies are focusing solely on creating software for these systems, building on top of the hardware of others. In time, many of these companies have discovered that a critical relationship exists between the hardware and the software capabilities in a robot. Furthermore, it is essential to select hardware that simplifies system integration, as well as meets power requirements and adapts to the changing demands of specific robotic applications.

Hardware acceleration

As semiconductor improvements have slowed below the pace predicted by Moore's law, robotics developers have turned to other methods to achieve higher performance, including the use of hardware accelerators. By creating specialized compute architectures that rely on specific hardware (i.e., through field-programmable gate arrays or FPGAs), hardware acceleration empowers faster robots, with reduced computation times (real fast, as opposed to real-time), lower power consumption and more deterministic behaviors.



With hardware acceleration and adaptive SoCs and SOMs, *building robotic behaviors involves programming an architecture that creates both the right data paths and control mechanisms.*

📷 | *Xilinx*

Mixed control and data

With hardware acceleration, the traditional control-driven approach for software development in robotics can instead be replaced with a mixed control- and data- driven process where custom compute architectures allocate the optimal amount of hardware resources for an application. This allows for more specialized, power-efficient, secure and higher performance robotic circuitry. To rephrase Alan Kay's famous quote about software development ("People who are really serious about software should make their own hardware."), if you are serious about robotics, you should build your own hardware at one or multiple levels, including the computational, mechanical and behavioral levels.

Mixed Computation

Table 1 compares the different computational models in robotics that illustrates how the mixed model provides the best trade-off between the various control and data-driven approaches. CPUs and GPUs excel in control flow computations, while FPGAs excel in data flow computations.

Various adaptive System-on-Chips (SoCs) and System-on-Modules (SOM) devices available from multiple vendors provide the best of both worlds for the mixed computational model. It is an approach for robotic computation that delivers the best of both worlds, the flexibility and full control of CPUs to implement complex computations, with the low power, high performance, low latency and deterministic nature of hardware acceleration. Examples include adaptive SoCs and SOMs from vendors such as AMD, Xilinx, MicroChip Technology and Qualcomm, among others.

With hardware acceleration and adaptive SoCs and SOMs, building robotic behaviors involves programming an architecture that creates both the right data paths and control mechanisms.

Hardware expertise a gating factor

With this new batch of SoCs, hardware acceleration has the potential to revolutionize the robotics sector in the coming years. Unfortunately, there is a caveat – complexity. The process of creating specialized compute architectures for robots using a mixed computational model is complex, often exceeding the engineering skills of robotics developers.

Utilizing advanced software engineering practices, roboticists can build complex real-time deterministic systems using languages such as C++. But, these developers often lack hardware and embedded systems expertise, which can hinder the adoption of hardware acceleration technologies.

Robot Operating System

To address this challenge and simplify hardware acceleration for roboticists, companies like Xilinx are focusing on Robot Operating System (ROS) and

Technology	CPUs	DSPs, GPUs, and AI Engines	FPGA	Adaptive SoCs (CPUs + FPGAs), ACAPs (CPUs + FPGAs + AI Engines
Definition	Scalar Von-Neumann processor. Conventional computing. A token of control indicates when a statement should be executed.	Vector Von-Neumann processor. Token of control for executing a vectorized single instruction. Fixed processing and memory architectures.	Flexible processing structures. Eager evaluation; statements are executed as soon as data is available.	Adaptive processing structures. Capability to build mixed control and data-driven compute models mixing different processors.
Programming Capabilities	SW-programmable	SW-programmable	HW-level programmable	SW-programmable and HW-level programmable
Advantages	1. Full control 2. Complex data and control structures are easily implemented.	1. Full control 2. Domain-specific parallelism (math, video, and image processing)	1. Very high potential for parallelism 2. High throughput 3. Deterministic: free from side effects	1. Full control capabilities 2. Complex data and control structures easily implemented 3. Very high potential for parallelism 4. High throughput 5. Deterministic 6. Domain-specific parallelism
Disadvantages	1. Less efficient in managing asynchronous events (interrupts alter computational cycles) 2. Limited parallelism scalability (# of CPU cores) and execution capability due to fixed control path	1. Fixed memory and compute architectures (efficiency bottlenecks) 2. GPUs cannot operate directly on real-time data streams typical of physical systems like robots 3. DSP implement specialized instructions, but suffer of the same trade-off frequency/performance	1. Long development cycle 2. Difficult to program and architect 3. Data flow is privileged versus control flow	1. Need allocation (often manual) of different tasks into different computing units to exploit performance 2. Require coordination among the different computing units (when, how, and where to get the data)

Table 1 is a comparison of hardware computational models in robotics. *Credit: Xilinx*

Gazebo. ROS, an open-source collection of software frameworks and tools, is the de facto standard for robotics software development.

Since 2020, and especially with the introduction of ROS 2, ROS has become the default Software Development Kit (SDK) for robotic applications across many industries. Most groups are using ROS and the simulation tool Gazebo in some way.

Rather than reinventing the wheel with new tools, frameworks and/or platforms to bridge the hardware acceleration complexity gap among robotics architects, Xilinx and others are leveraging the power of ROS 2. Organizations like the ROS 2 Hardware Acceleration Working Group (HAWG) have been created, with initial objectives and goals announced publicly (proposal, working group announcement) and an open architecture developed. The architecture proposed aims to be platform-agnostic (for edge, workstation, data center and/or cloud targets), technology-agnostic (FPGAs, CPUs, and GPUs) and easily portable to other boards.

Hardware acceleration via ROS 2

The process of creating optimized, hardware specific, compute architectures for robotics systems can be time consuming and complex, and can act as a gating factor for continued robotics innovation. Companies, associations and others are working hard to simplify and speed the process.

The work of the ROS 2 Hardware Acceleration Working Group – namely, driving the development of acceleration kernels for ROS 2 and Gazebo – holds much promise. ROS is an open standard that has been widely embraced by the robotics development community, including, with the introduction of ROS 2, a growing number of commercial and industrial robotics systems developers. RR

About the Author

Víctor Mayoral-Vilches *is the robotics system architect at Xilinx. With a strong technical background in robotics, embedded systems and cybersecurity, he spent the last 10 years building robots. Prior to joining Xilinx, he founded and led 3 robotics startups building teams of 30+ engineers and leading them across research initiatives and projects in the fields of robotics, cybersecurity and artificial intelligence.*

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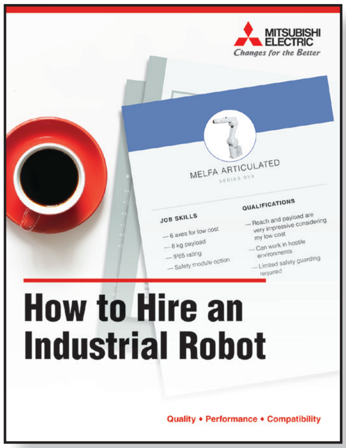

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3 tips to developing outdoor robots for unstructured environments

***Scythe Robotics shares tips about sensor selection, ruggedized hardware,** and software optimization for its commercial mowers.*

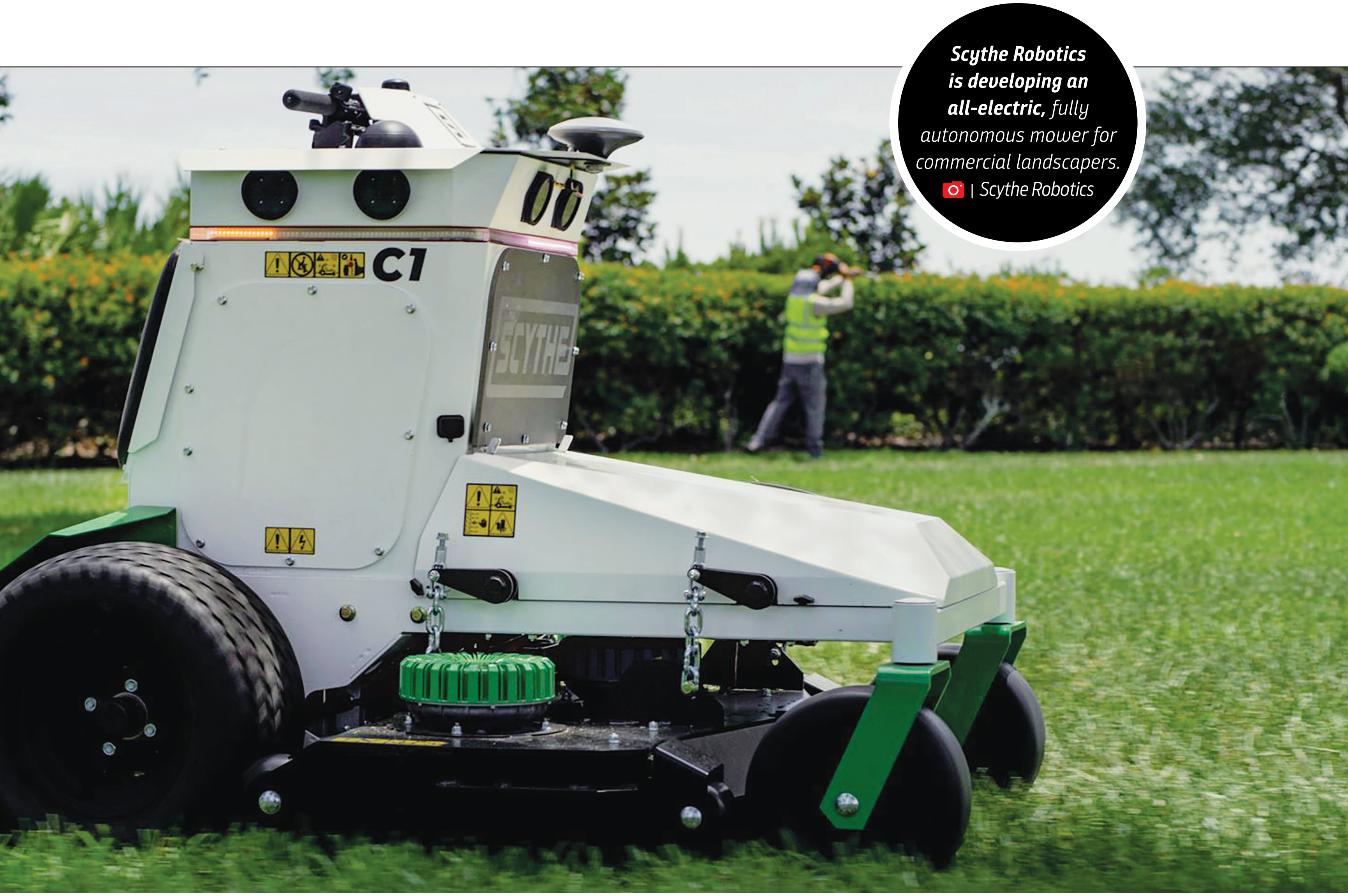
Jack Morrison • Co-Founder, *Scythe Robotics*

Every roboticist has heard about the three Ds: dull, dirty and dangerous tasks we'd be better off having robots do for us. Across off-road industries like landscaping, agriculture and forestry, people have to perform repetitive work in incredibly uncomfortable conditions, often with the risk of dangerous accidents. Faced with additional challenges from worker recruitment and retention to worker safety and efficiency, these industries present huge opportunities for robotics.

From landscape maintenance today to trash pickup and forest fire mitigation tomorrow, autonomous outdoor robots can help humanity take far better care of the environment. But building robots to complete tasks like these in unstructured, off-road environments presents design challenges different from those encountered in structured environments like warehouses and factories and on-road environments like streets and sidewalks.

At Scythe Robotics, we are building autonomous solutions for off-road environments, focusing first on a self-driving mower for commercial landscaping — an all-electric, zero-emission solution for businesses on the frontline of green space management. Commercial landscaping, an enormous $105 billion industry, is filled with dull, dirty and dangerous challenges. It also faces labor shortages that are straining businesses and hamstringing growth.

There are three keys to designing our mowers that we'll share for developing robots to tackle the complexities of unstructured, off-road environments.



***Scythe Robotics* is developing an all-electric,** *fully autonomous mower for commercial landscapers.* | Scythe Robotics

1 Different jobs require different machines

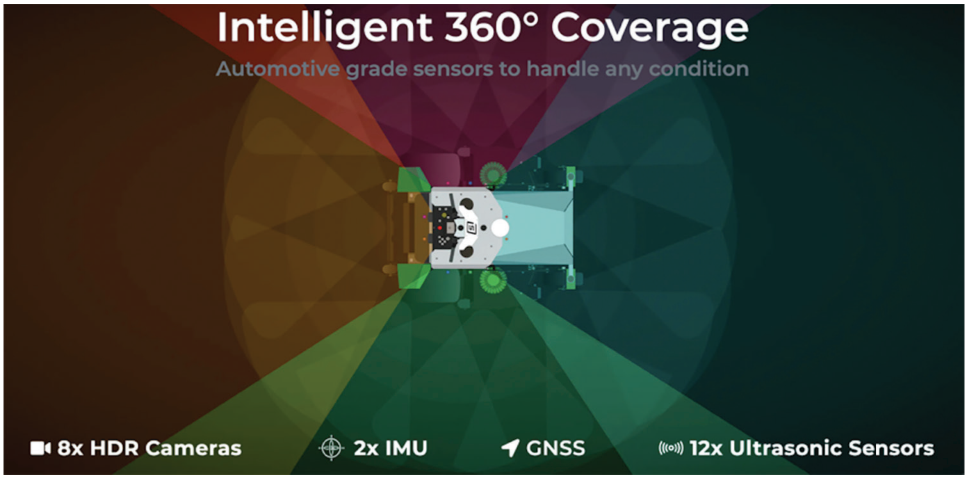
Our robots must be incredibly rugged to be successful in the landscaping environment. They maneuver over rough ground, mow under the blazing sun in high temperatures, and have to operate without allowing any ingress from grass, dust, or downpours. It's often cost-prohibitive to design a machine that's ideal for all scenarios, so you have to deeply understand your potential operating conditions as a part of the requirements.

And unlike typically flat and relatively predictable indoor environments, a general-purpose robotic platform won't cut it off-road. The variety of requirements for off-road tasks means hardware choices must be made based on factors such as traction, stability, speed and weight distribution. Designing the hardware for our off-road mowers, we considered things like what terrain we needed to cover, how gentle we needed to be on the turf to avoid tearing up grass, and how steep of a hill we'd need to climb. Even two mowers, for example a general commercial mower and a specialty golf course fairway mower, can have wildly different requirements.

2 Dynamic perception challenges inform sensor selection

Creating an autonomous robot that can go back and forth in straight lines is table stakes for mowing. The real challenge for mowing autonomy is operating safely in a dynamic, unstructured environment. Persistent, high-def 3D mapping like what's often used in on-road driving isn't nearly as effective thanks to the ever-changing nature of outdoor landscapes. So highly detailed, real-time live perception is a must-have.

Our machines have eight high-dynamic-range (HDR) cameras that can see under any circumstances. Typical machine vision cameras with 60dB range are insufficient for the stark lighting differences between shadows and direct


Intelligent 360° Coverage
Automotive grade sensors to handle any condition
8x HDR Cameras
2x IMU
GNSS
12x Ultrasonic Sensors

A diverse sensor array helps Scythe's robot mowers *navigate off-road environments.*

| *Scythe Robotics*

sunlight – a frequent occurrence off-road.

The ruggedness of the environment must also inform sensor selection. Sensors must work in all possible operating conditions. And detection for fouled sensors, like a mud-covered camera, needs to be built in. We chose ultrasonic sensors as a secondary sensing layer precisely because they work robustly in so many conditions and complement the detail of cameras well.

3 Optimize software processing to match the task

Off-road applications can be incredibly power intensive, whether it's spinning mowing blades at 4000rpm or hauling heavy loads up steep grades. Oftentimes there is limited ability to charge nearby, which can be challenging for emissions-free, fully-electric machines. This forces power savings in other possible areas, such as compute capabilities. Instead of packing beefy desktop GPUs, off-road mobile robots must make do with substantially lower power devices.

The limited available compute means the software must be heavily optimized for performance, as well as reliability. Fast response times, in the sub-100ms range, from perception to action are crucial for safe operation in ever-changing environments. This makes some choices of robotic software tooling, like the Python language, unsuitable for these environments. We lean heavily on the highly-performant Rust programming language because it gives us speed without sacrificing safety and reliability.

Oftentimes, software for robots needs to take advantage of the unique constraints available. For instance, unlike on-road operations where simply coming to a rapid stop can be dangerous, many off-road autonomous applications allow for simpler safety fallback behaviors. In mowing, we can simply brake the machine and stop the blades if the system is at all unsure about its ability to operate safely. This is a huge advantage, allowing us to be more conservative in our safety parameters and deploy machines early on, without waiting for perfection.

Looking ahead, we believe we are at a tipping point where businesses with dull, dirty and dangerous jobs will face increasingly severe labor shortages. But their work is often critical for taking care of our environment and producing many of our most important goods. Automation can offer many transformative solutions to enable businesses to grow while nurturing the planet. Scythe mowers are at the forefront of this movement with machines in the field today. Similar large opportunities exist across many other off-road industries, too, for new innovators to step up and tackle. **RR**

About the Author

Jack Morrison *is the co-founder & CEO of Scythe Robotics, a Boulder, Colo.-based startup developing autonomous outdoor robots for off-road environments. Prior to founding Scythe, Morrison spent three years at Occipital as a computer vision engineer. He received a B.A. in computer science from Bowdoin College in 2011.*

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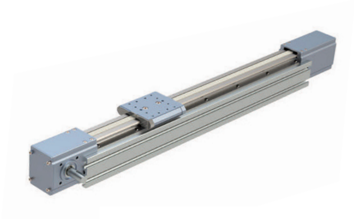

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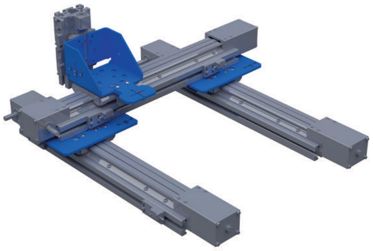

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12 major warehouse-focused AMR acquisitions

***Had Amazon not purchased Kiva Systems in 2012,** many of today's AMR companies might not exist.*

Steve Crowe • Editorial Director, *The Robot Report*

One thing has become abundantly clear in 2021: autonomous mobile robots (AMRs) are in high demand. Locus Robotics recently acquired fellow AMR provider Waypoint Robotics for an undisclosed amount. New Hampshire-based Waypoint became the fourth AMR company acquired in a five-month span.

The Robot Report compiled 12 of the more notable acquisitions of AMR companies. There have been plenty of companies acquired that develop AMRs for other applications, such as agriculture, or enabling technologies for AMRs. Heck, Boston Dynamics is technically an AMR, but it uses legs to move around. This recap focuses specifically on companies selling wheeled AMRs that can freely navigate around a warehouse in material handling applications. No ASRS acquisitions welcome here.

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2A
3A
4A
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2446
WAYPOINT
MAV3K

Mobile Robots

Acquirer	Acquired	Amount ($M)	Date
Locus Robotics	Waypoint Robotics	--	9/20/21
ABB	ASTI Mobile Robotics	190	7/20/21
Zebra Technologies	Fetch Robotics	290	7/1/21
JASCI Software	NextShift Robotics	--	5/4/21
Shopify	6 River Systems	450	9/9/19
Teradyne	AutoGuide Mobile Robots	58	10/21/19
Amazon	Canvas Technology	100	4/11/19
Teradyne	Mobile Industrial Robots	272	4/26/18
Omron	Adept	200	9/16/15
KUKA	Swisslog	357	9/25/14
Amazon	Kiva Systems	775	3/19/12
Adept	MobileRobots	--	6/14/10

The table above is arranged by date, starting with the most recent. Below the table is a short recap about the significance of each deal.

Locus Robotics acquires Waypoint Robotics: Wilmington, Mass.-based Locus Robotics is a leading AMR developer. It's raised approximately $305 million since it was founded in 2014 and is valued at more than $1 billion. Earlier in 2021 after closing a $150 million Series E round, Locus said it had 4,000 AMRs out in the field and 40-plus customers. It also recently announced an expanded partnership with DHL.

Locus has done all of this with just one AMR form factor with limited payload capacity. Waypoint brings multiple form factors and heavy-duty payload capacity to the table, which will open up new markets to Locus and expand its deployments with existing customers.

ABB acquires ASTI Mobile Robotics: ABB, one of the world's biggest automation companies, has focused mainly on large industrial robot arms and collaborative robot arms. As Sami Atiya, CEO of ABB Robotics said on *The Robot Report Podcast*, more of ABB's customers began asking about mobile robots. Buying ASTI, rather than developing its own solutions, gives ABB a quick and respected way to diversify its robotics portfolio to provide more value to existing and new customers.

Zebra Technologies acquires Fetch Robotics: Fetch and Zebra worked closely together prior to this acquisition. In fact, Zebra already owned a 5% stake in Fetch before paying $290 million for the other 95% stake. Zebra was already a leading provider of warehousing solutions, but adding Fetch's various AMRs gives Zebra more tools in its toolbox, becoming more of a one-stop shop for warehousing technology needs.

JASCI Software acquires NextShift Robotics: This was an interesting acquisition for a number of reasons, but primarily because NextShift Robotics seemingly flatlined the last couple of years. JASCI is an experienced software company with an established sales channel and customer base. It acquired NextShift to offer both logistics software and robotics hardware in a single platform that it calls "ALIDA."

Shopify acquires 6 River Systems for $450M: As far as we can tell, this is the second-most expensive acquisition behind only Amazon's purchase of Kiva Systems for $775 million in 2012. In fact, two of 6 River Systems' three co-founders – Rylan Hamilton and Jerome Dubois – worked at Kiva Systems for a number of years. So 6 River Systems had deep knowledge of the logistics space when it launched.

Shopify paid nearly a half-billion dollars for the acquisition to help its customers compete with Amazon. In June 2019, Shopify launched its Fulfillment Network service that it said will speed up delivery times and lower shipping costs for its customers. Shopify's fulfillment centers, which are located throughout the U.S., support merchants that ship between 10 and 10,000 packages per day.

Teradyne acquires AutoGuide Mobile Robots: Teradyne acquired AutoGuide Mobile Robots, which offers heavy-duty AMRs, to complement the lighter-duty AMRs from Mobile Industrial Robots (MiR), which Teradyne acquired a year earlier. Interestingly, MiR recently launched two heavy-duty AMRs and AutoGuide has struggled to meet expectations. Teradyne's industrial automation portfolio is quite strong, however, thanks to MiR and collaborative robotic arm leader Universal Robots.

Amazon acquires Canvas Technology: Amazon bought Boulder, Colo.-based startup Canvas Technology for more than $100 million in 2019. Canvas' first product was an autonomous cart it claimed could operate without relying on a prior map. Canvas' autonomous cart seems like a perfect way to augment the person-to-goods workflow in Amazon warehouses. Of course, the company's autonomous navigation technology is a great fit, too, and could be used on other systems such as Amazon's Scout delivery robots.

Teradyne acquires MiR: Teradyne has doubled down on AMRs with its acquisitions of MiR and then AutoGuide. MiR has proven to be a better play to this point, having earned $16 million in Q2 2021 and $14 million in Q1 2021. MiR is on pace to generate $60 million in revenue this year after growing sales 1% to $45 million during pandemic-stricken 2020.

Omron acquires Adept Technology: At the time of this acquisition, Kyoto, Japan-based Omron had annual revenues of $7.3 billion, of which $2.7 billion was from its industrial automation business. Its industrial automation portfolio in 2015 consisted of delta, gantry and SCARA robots, as well as vision components and systems. Adding Adepts AMRs to its lineup diversified Omron's automation portfolio.

KUKA acquires Swisslog for $357 million: The Swisslog acquisition added a mobility arm to KUKA's arsenal of products, a strategic move other traditional robot arm manufacturers have made and continue to make today (see ABB). KUKA had a mobile robot of its own at the time, but it was more a work-in-progress compared to those offered by Swisslog. At the time, Swisslog primarily operated in healthcare- and warehouse distribution-related applications. In mid-2016, Chinese Midea Group acquired a majority stake in KUKA.

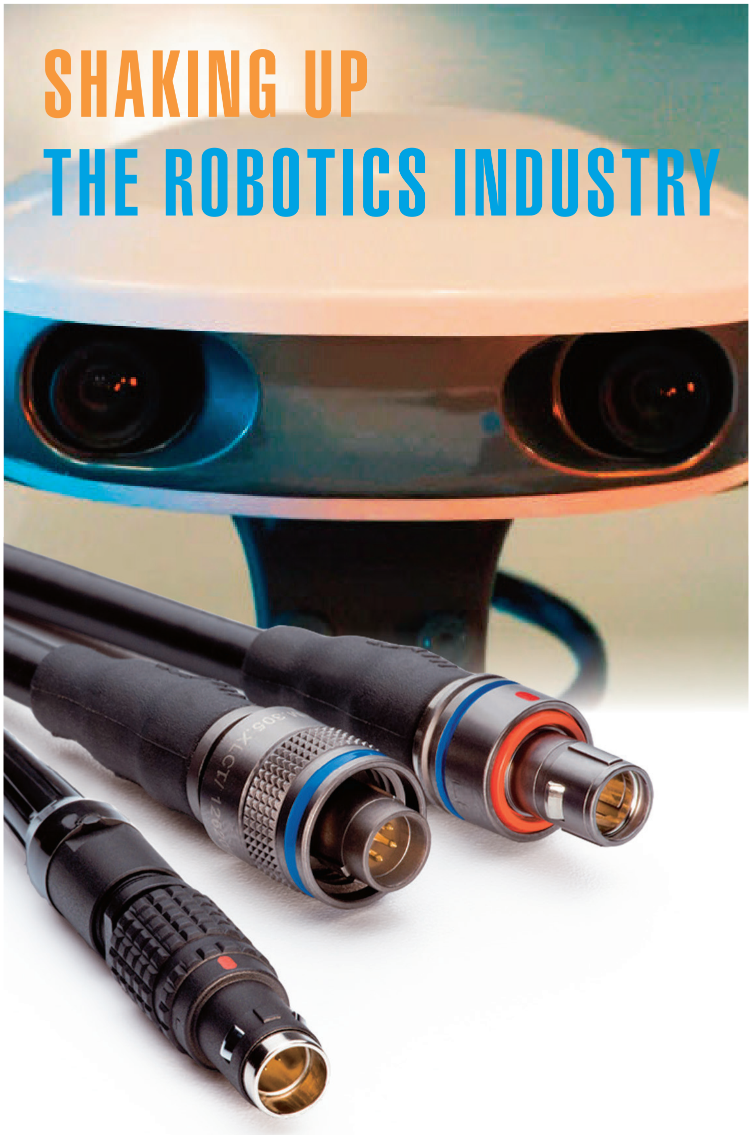
Amazon acquires Kiva Systems: Kiva Systems' robots don't navigate the same way the AMRs on this list do. The Kiva robots are technically automated guided vehicles (AGVs), but this acquisition played such a crucial role in the development of today's AMR industry that we included it on the list.

At the time of the deal, Kiva said it would continue to sell its solution to third-party companies. Of course, that didn't happen. Amazon renamed Kiva Systems to Amazon Robotics and the technology is now used solely in-house. This left a technology gap in the industry, which led to the creation of various warehouse automation startups.

Locus Robotics and 6 River Systems are perhaps the best examples of the trickle down effect caused by this deal. Quiet Logistics, a 3PL, used Kiva robots at a warehouse in Massachusetts. After its Kiva robots were no longer supported, it took matters into its own hands and developed its own robots. It ran this project in stealth for about three years before spinning out Locus Robotics.

Had Amazon not purchased Kiva Systems, Locus Robotics and many others in the space might not exist today.

Adept Technology acquires MobileRobots: At the time of the deal, Adept Technology had about $50 million in sales of SCARA, parallel and other fixed-position robots. It added a complete line of AGVs and AMRs to its portfolio with the acquisition of MobileRobots in 2010. Five years later, Adept was acquired by Omron for $200 million. RR



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5 AMRs improve scalability, safety of Mirgor's intralogistics

***Argentinian manufacturer replaced aging manually-driven technology** with mobile robots and a fleet management system.*

Mike Oitzman • Editor, *Robotics*

Mirgor is an Argentinian technological company that manufactures and distributes consumer electronics and auto parts. It also exports agricultural commodities and oil seeds.

Challenge

Mirgor is based in the province of Tierra del Fuego, Argentina, with factories in Rosario City and headquarters in Buenos Aires. The plant's workers experienced different safety risks with the old, nearly manual supply system. The locomotive cars transported screens and rear television covers through busy routes with little order. Even before thinking about acquiring new technologies, the company believed there was no more efficient way to optimize its processes or scale them over time for future developments.

"At Mirgor, we took the time to analyze what kind of automated solutions could be applied to repetitive tasks to ensure an uninterrupted workflow," said Julio Haberle, plant manager, Mirgor. "MiR´s robotic systems have not only accelerated the tasks carried out in our facilities, but have also improved the safety of our workers and optimized the supply capacity of materials for our production line to the maximum."

The implementation of autonomous mobile robots (AMRs) was a great challenge that broke the paradigm of maintaining obsolete technologies or methods for many years due to being considered "functional." Mirgor realized that, according to its type of material

The MiR200 Hook autonomous mobile robot can transport up to 1100 lb (500 kg) *at a maximum speed of 2.5 MPH.*

📷 | *Mobile Industrial Robots*

transportation tasks, these applications could be fully automated without the need for any worker to intervene directly.

Mirgor's objective was to improve the safety of its workers and optimize the intralogistics routes of materials for the assembly of smart TV screens to its production line. But with an obsolete and dangerous transportation process, high accident rates were generated.

Solution

Now, with four MiR200 Hooks and one MiR500 managed through Mobile Industrial Robots' (MiR) fleet platform, Mirgor's internal transport has a simple and centralized online configuration. Mirgor has also eliminated bottlenecks and interruptions thanks to the uninterrupted operation of the AMRs.

"With the adoption of these new technologies, we can now easily program and control our fleet of robots," said Miguel Santana, maintenance manager, Mirgor. "We can also manage our robots with different top modules, hooks or other accessories that facilitate the transportation of the materials we need as they arrive quickly and in accordance with the requirements of our workers on the production line."

"Our robots maneuver safely, avoiding collisions with people and obstacles, going through doors, and entering and leaving crowded areas," Haberle added.

"We are also able to download the CAD files of the building plan directly to the robots and program them using the simple online interface, the use of which does not require programming experience. It is possible to adapt the robot's mission easily using a smartphone, tablet or computer connected to the network."

Five mobile robots helped Mirgor eliminate intralogistics bottlenecks and interruptions *and improve safety for its employees.* 📷 | *Mobile Industrial Robots*

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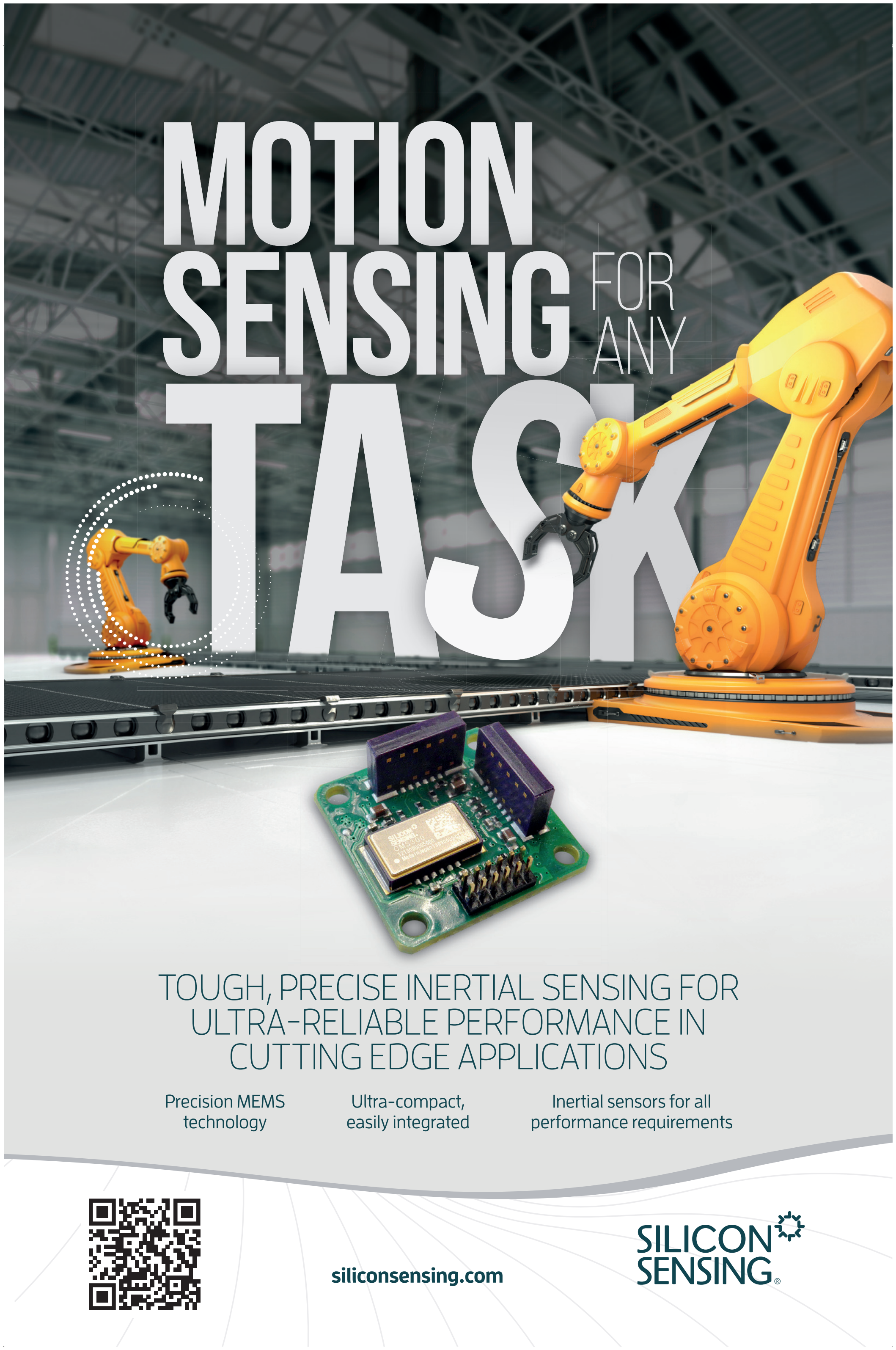
Macon, a certified MiR systems integrator, provided the necessary support for the deployment of AMRs at the Mirgor plant.

"A new generation of autonomous mobile robots is changing the way businesses transport materials within their facilities, and MiR robots are leading the way," said Emiliano Herrero, sales director, Macon. "With extraordinary flexibility and smart technology, MiR's AMRs can be used in virtually any situation where employees are in charge of pushing carts or making deliveries. Now it is possible to automate these tasks, so that employees can focus on higher value activities."

Results

MiR robots are safe and cost-effective mobile robots that quickly automate internal transport and logistics tasks. The robots optimize workflows, freeing up staff so the company could increase productivity, safety, and optimize the supply of materials to its processes.

"More and more companies are benefiting from one of Industry 4.0's favorite technologies: mobile autonomous robots. At Mirgor we couldn't let more time go by to stay competitive in the market and MiR undoubtedly represents a great ally in this work that drives us to improve day by day. We will undoubtedly share our experience on the application of this technology in all our plants to continue carving out a profitable future within our industry.", Julio Haberle points out. Over the years, Mirgor has developed an excellent logistics capacity, building strategic alliances with multinational companies around the world, and, above all, a production culture based on the demanding requirements of the electronics industry. RR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Locus Robotics on target with Waypoint acquisition

***The two companies offer compatible solutions** that will extend Locus' portfolio of autonomous mobile robots.*

Mike Oitzman • Editor, *Robotics*

Locus Robotics recently acquired Waypoint Robotics. This is going to be a great combination of compatible technologies, market focus and skillset/personalities. Here's why.

Locus has built a reputation as one of the leaders in the warehouse automation space. The company has raised $305M since its founding in 2014. The company is one of the first AMR unicorns with a valuation over $1B.

Locus is also one of the market leaders in commercializing the robots-as-a-service (RaaS) business model. In a RaaS business model, clients pay for the service delivered by the solution, instead of paying to acquire a capital asset, and then amortizing/depreciating the cost of that asset. Locus recently celebrated half-a-billion picks by LocusBots, proof that customers value the Locus solution.

For Locus' customers, leveraging RaaS means they can pay for the automation service out of operating expense budgets, instead of capital expense budgets. But, it also has the side effect of reducing risk for the customer with a new technology. In other words, it's easy to remove the solution if it doesn't work. This basic tenet is what aligns a RaaS-based business model so tightly with the success of the client.

LOCUS
WAYPOINT ROBOTICS
WAYPOINT VECTOR

Locus Robotics added heavy duty payload capabilities to its lineup *with the acquisition of Waypoint Robotics.* 📷 | *Locus Robotics*

Deconstructing RaaS
From this simple idea, Locus has built a very healthy business and a committed customer base. However, RaaS isn't ideal for every application. To be a successful RaaS solution, the operation requires three success factors:

① The problem must be scalable.

② The Service Level Agreement (SLA) must be measurable and funded by an operating expense.

③ Output must be guaranteed – i.e. there has to be strong commitment from the vendor to identify, intercept and prevent failures from happening.

The business model for RaaS is simple. Customers pay a monthly, quarterly or yearly fee, based on the amount of work done by a Locus robot. We don't know exactly what Locus' installed robot population looks like, nor what the average contract cost is. However, Table 1 outlines three possible yearly revenue outcomes based on the population of 5000 robots and an average cost per hour, single shift contract between $5-$9/hour.

Locus has evolved an efficient fleet management and order management software stack to manage the warehouse workflow of both human associates and LocusBots. Leveraging artificial intelligence, this is the part of the system that decides how to organize the warehouse operations each day and then assign the robots to help the human associates in an optimized picking order. Locus has its roots in e-commerce, so it understands how to optimize inventory workflow through the warehouse.

The unseen part of the Locus software stack is its remote operations center (ROC). This is the layer of software used by the Locus support team and customer success team to monitor, troubleshoot, update and support the robots on the floor – remotely.

The biggest advantage of a RaaS company, like Locus, is that it has access to how solutions are operating in the field, every hour of every day, for every customer. Aggregating this data,

	Scenario 1	Scenario 2	Scenario 3
Robot Population	5,000	5,000	5,000
Cost per hour	$5	$7	$9
Hours per year	2,080	2,080	2,080
Revenue/robot per year	$10,400	$14,560	$18,720
Total revenue per year	52,000,000	72,800,000	93,600,000

Table 1 – Simple RaaS business model with 5000 robot population. | *Credit: The Robot Report*

Founded in 2014, Locus Robotics recently surpassed half-a-billion picks. | *Locus Robotics*

Locus product managers have the ability to see trends and to prioritize the product enhancements that will have immediate and wide ranging impact. It's a product manager's dream scenario. If certain elements of the robot are failing prematurely, they know about it and can react preemptively to maintain customer satisfaction.

Waypoint's journey

Waypoint Robotics has built a reputation for well-engineered solutions. You might call it a "roboticist's robotics" company. The system was built to be a mobile platform for any number of AMR applications.

Up to this point, the company has only sold its solutions in a classic capital expenditure business model. Waypoint clients buy the AMRs and own them. This enables the client to customize the payload on the AMR and to deploy it into any application it chooses. Since its inception, Waypoint has focused on omnidirectional motion as the basis and differentiator for its solutions using mecanum wheels. This fundamental design decision has both advantages and disadvantages in terms of the types of applications and work environments that the robot can operate in.

Omnidirectional motion for an AMR is desirable when there are tight aisles to navigate, or when approach paths to a "waypoint" are limited. A good use for an omnidirectional AMR is in machine tending with a mobile manipulator, and Waypoint has a number of AMRs in production for customers.

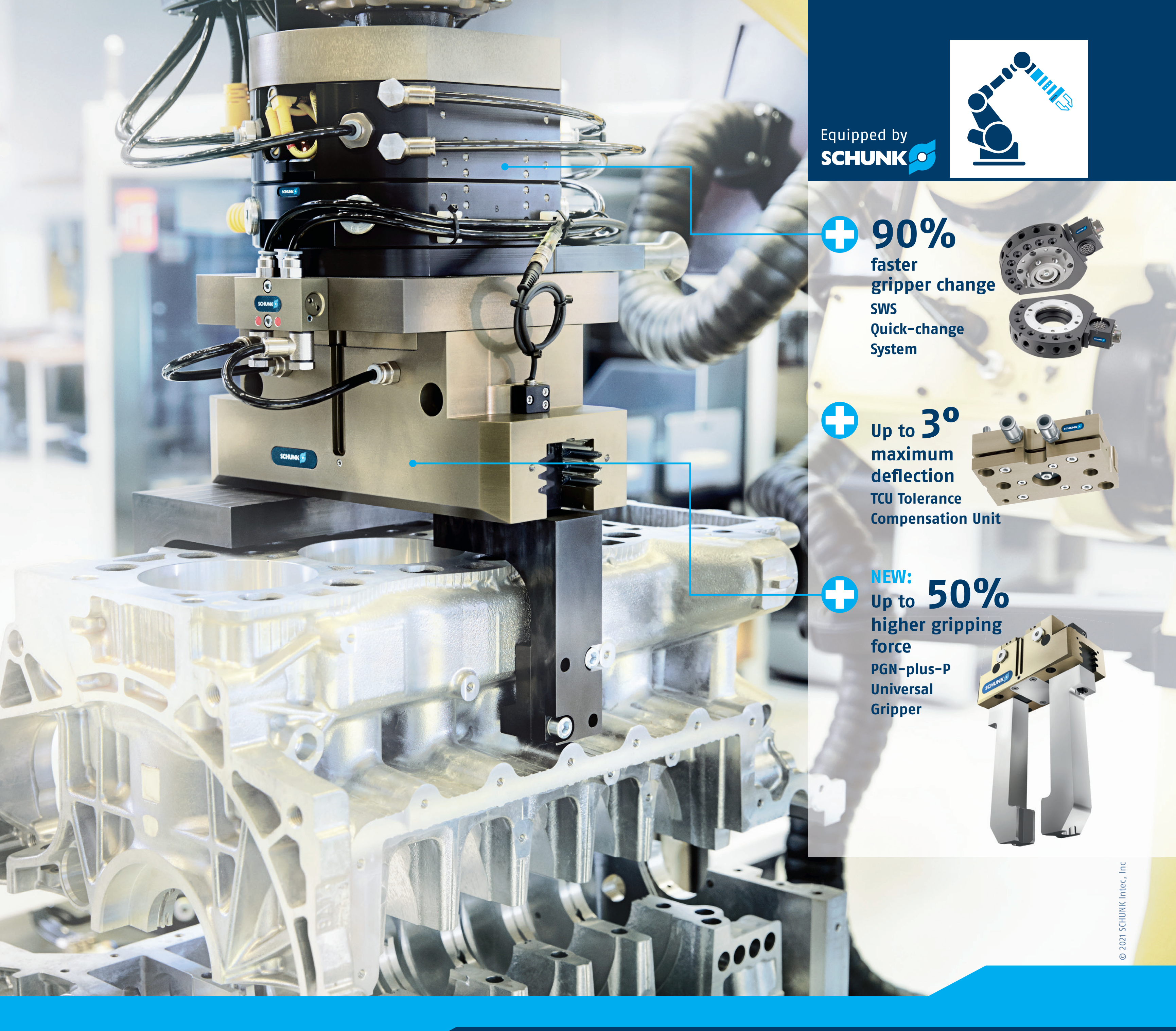
On most machine shop floors, there often isn't a lot of floor space available in front of the machine. This makes it difficult for other styles of AMRs to approach the target.

As a result of the design choices, Waypoint has found success in many manufacturing applications such as work-in-process handling, tray handling, machine tending and finished goods movement.

In addition, Waypoint also has a heavy payload platform with the MAV3K AMR (3000 lb. payload capacity). The MAV3K can handle fully loaded pallets or it can be a mobile assembly base for large items such as appliances, or car/aviation parts.

A compatible union?

When you put both companies side by side, it's easy to see why this is going to be a compatible union. Currently, there is little to no overlap in the products and markets served. Yet, there are immediate



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opportunities for green field sales of the Waypoint product line into the existing (and future) Locus customer base. The immediate opportunity is to bring the MAV3K AMR under the supervision of the Locus fleet management solution and deploy it into one of two possible warehouse workflows:

① Add the Locus UI to the MAV3K and deploy it into heavy payload person-to-goods warehouses. In this scenario, the MAV3K becomes a "LocusBot3K" that can lead an associate to pull items from inventory that are too heavy for the current LocusBot model.

② Deploy the MAV3K into new warehouse workflows, moving heavy mixed load or unit load pallets around the warehouse, including to/from the shipping dock.

Other intralogistics workflows become possible now with the integration of Waypoint's AMRs and Locus' software. Both solutions are built on top of the Robot Operating System (ROS).

According to Jason Walker, CEO and co-founder of Waypoint, the company will continue to sell Waypoint solutions into the manufacturing market. The company has some well established customers within the manufacturing market. The added credibility of being a part of the Locus family should help reduce the barriers to acceptance, reduce the risk for new clients, and shorten sales cycles.

A few bumps in the road ahead

What's yet to be determined is how the organizations will combine their sales and support teams. This is where a clash of cultures and processes between a RaaS-based sales model and a capital equipment sales model may pose some hurdles. It will be interesting to watch what type of hybrid selling and support model emerges from this union.

One thing is clear, the companies should have a nice fit of corporate cultures since they are both based in the northeast – in fact, the current corporate headquarters are a 40-minute drive from each other. Both organizations have strong ties to the Boston robotics community and to MassRobotics. This was likely one key factor in both the introduction of the companies as well as the potential for a successful integration.

Robotics acquisitions heats up

Are there other acquisitions on the horizon? That's an easy yes. There are a number of undervalued robotics-related companies. This includes both AMR suppliers, as well as peripheral, sensor and software suppliers.

Within the warehousing space, there are still a number of warehouse management software (WMS) providers that are currently software-only solutions. The core of Locus' technology is, after all, its WMS. There are a number of WMS competitors on the market who could make a similar play; pick up a standalone AMR company and fully integrate it into its workflow.

Similarly, as we witnessed earlier this year with the acquisition of Fetch Robotics by Zebra Technologies, there are any number of warehouse component suppliers who might want a bigger piece of the warehouse systems play.

Finally, there are a number of robotic-based warehouse inventory counting solutions, including companies like Ware Robotics, that are one more piece of the puzzle. Any one of these companies might be a likely acquisition for Locus or other warehouse solution leaders in the near future. RR

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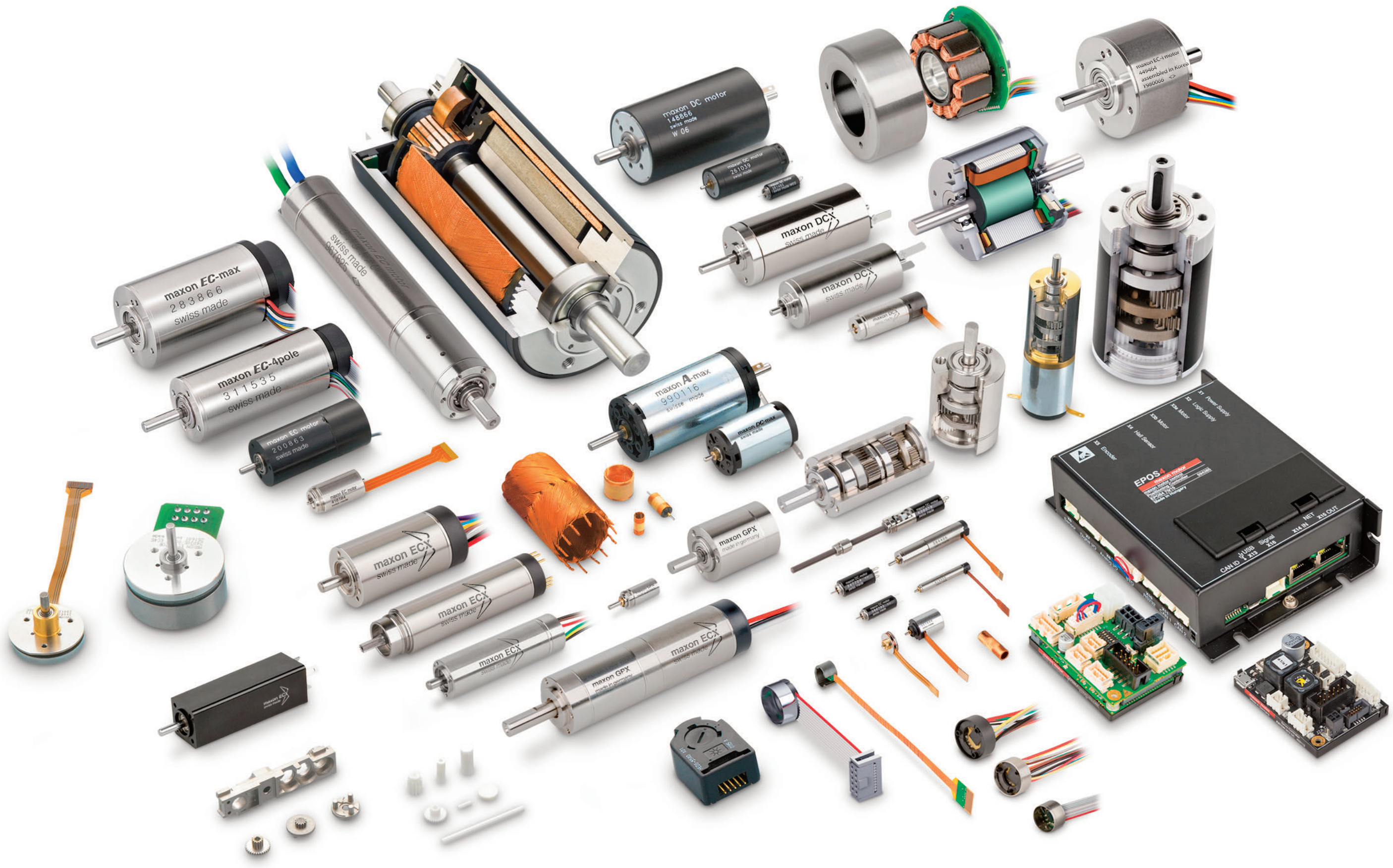

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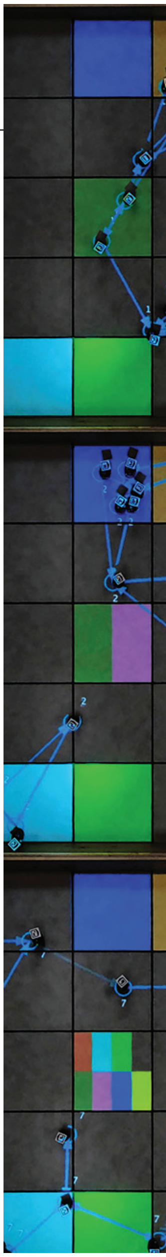
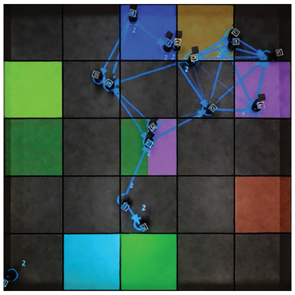


Can blockchain secure communications for robot fleets?

Even when follower robots were initially misled by malicious leaders, *the transaction-based system enabled all followers to eventually reach their destination.*

Steve Crowe • Editorial Director, *The Robot Report*



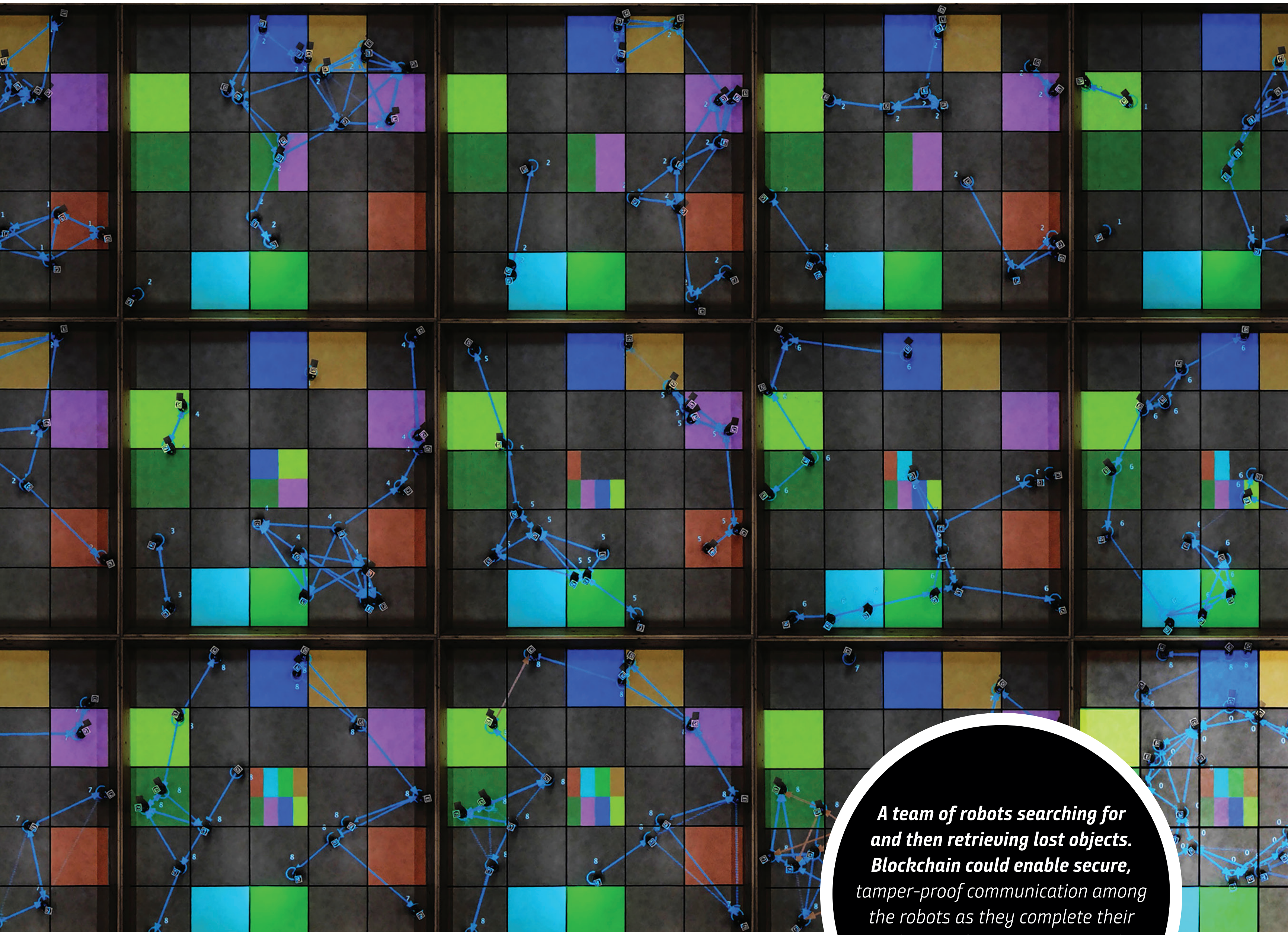
Imagine a team of autonomous drones equipped with advanced sensing equipment, searching for smoke as they fly high above the Sierra Nevada mountains. Once they spot a wildfire, these leader robots relay directions to a swarm of firefighting drones that speed to the site of the blaze.

But what would happen if one or more leader robots was hacked by a malicious agent and began sending incorrect directions? As follower robots are led farther from the fire, how would they know they had been duped?

The use of blockchain technology as a communication tool for a team of robots could provide security and safeguard against deception, according to a study by researchers at the Massachusetts Institute of Technology (MIT) and Polytechnic University of Madrid. The research may also have applications in cities where multi-robot systems of self-driving cars are delivering goods and moving people across town.

A blockchain offers a tamper-proof record of all transactions — in this case, the messages issued by robot team leaders — so follower robots can eventually identify inconsistencies in the information trail.

Leaders use tokens to signal movements and add transactions to the chain, and forfeit their tokens when they are caught in a lie, so this transaction-based communications system limits the number of lies a hacked robot could spread, according to Eduardo Castelló, a Marie Curie Fellow in the MIT Media Lab and lead author of the study.



A team of robots searching for and then retrieving lost objects. Blockchain could enable secure, *tamper-proof communication among the robots as they complete their task, according to new research.*

| *MIT/Polytechnic Institute*

“The world of blockchain beyond the discourse about cryptocurrency has many things under the hood that can create new ways of understanding security protocols,” Castelló said.

Blockchain not just for Bitcoin

While blockchain is typically used as a secure ledger for cryptocurrencies, in its essence it is a list of data structures, known as blocks, that are connected in a chain. Each block contains information it is meant to store, the “hash” of the information in the block, and the “hash” of the previous block in the chain. Hashing is the process of converting a string of text into a series of unique numbers and letters.

In this simulation-based study, the information stored in each block is a set of directions from a leader robot to followers. If a malicious robot attempts to alter the content of a block, it will change the block hash, so the altered block will no longer be connected to the chain. The altered directions could be easily ignored by follower robots.

The blockchain also provides a permanent record of all transactions. Since all followers can eventually see all the directions issued by leader robots, they can see if they have been misled.

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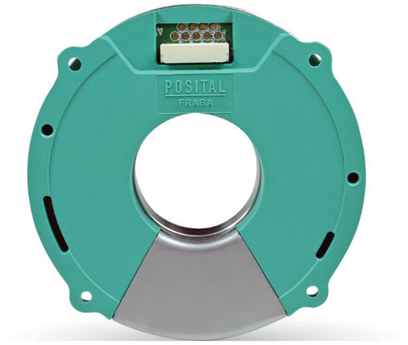

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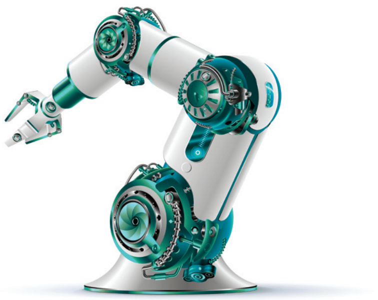

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For instance, if five leaders send messages telling followers to move north, and one leader sends a message telling followers to move west, the followers could ignore that inconsistent direction. Even if a follower robot did move west by mistake, the misled robot would eventually realize the error when it compares its moves to the transactions stored in the blockchain.

Transaction-based communication

In the system the researchers designed, each leader receives a fixed number of tokens that are used to add transactions to the chain — one token is needed to add a transaction. If followers determine the information in a block is false, by checking what the majority of leader robots signaled at that particular step, the leader loses the token. Once a robot is out of tokens it can no longer send messages.

"We envisioned a system in which lying costs money. When the malicious robots run out of tokens, they can no longer spread lies. So, you can limit or constrain the lies that the system can expose the robots to," Castelló said.

The researchers tested their system by simulating several follow-the-leader situations where the number of malicious robots was known or unknown. Using a blockchain, leaders sent directions to follower robots that moved across a Cartesian plane, while malicious leaders broadcast incorrect directions or attempted to block the path of follower robots.

The researchers found that, even when follower robots were initially misled by malicious leaders, the transaction-based system enabled all followers to eventually reach their destination. And because each leader has an equal, finite number of tokens, the researchers developed algorithms to determine the maximum number of lies a malicious robot can tell.

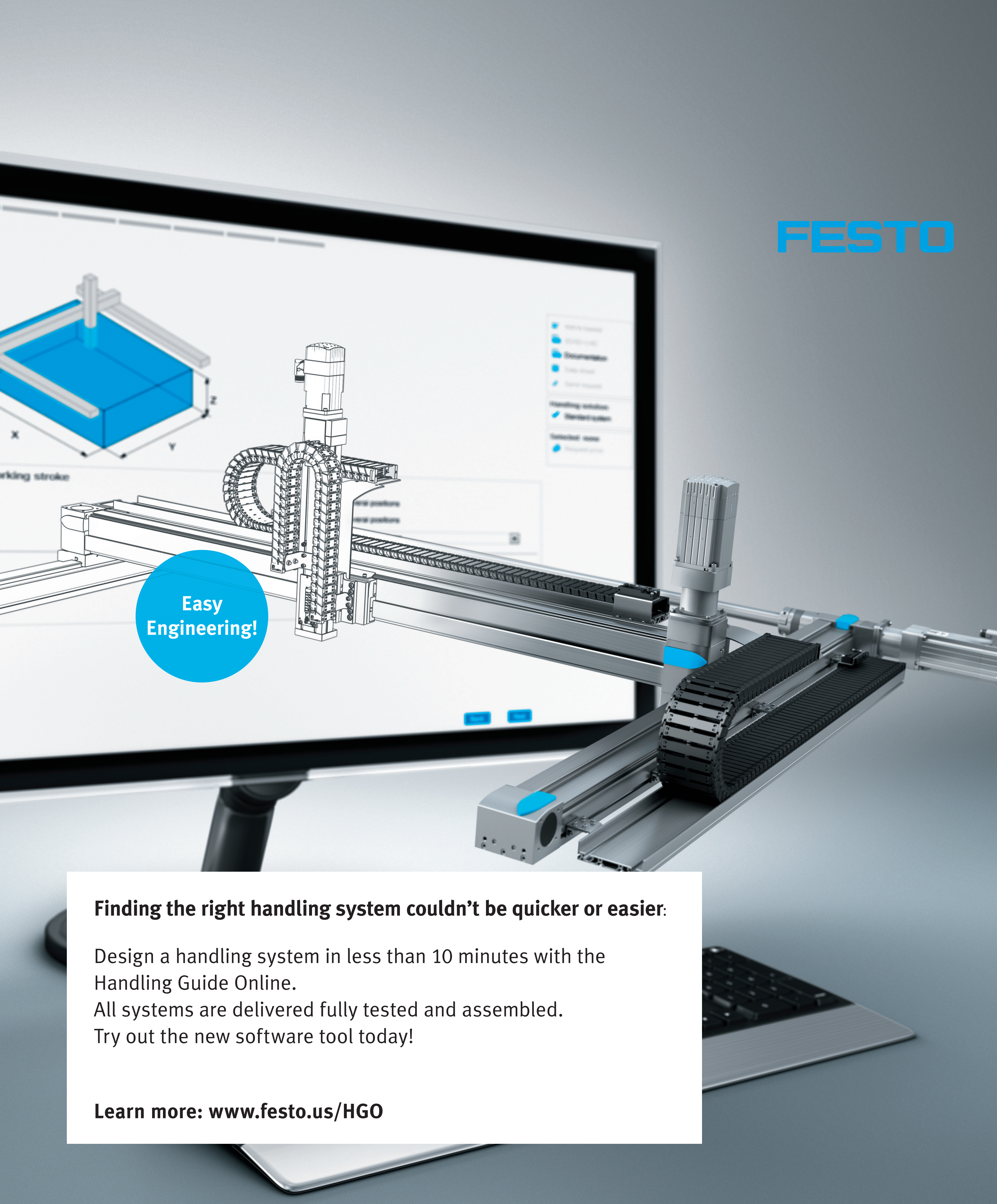
"Since we know how lies can impact the system, and the maximum harm that a malicious robot can cause in the system, we can calculate the maximum bound of how misled the swarm could be. So, we could say, if you have robots with a certain amount of battery life, it doesn't really matter who hacks the system, the robots will have enough battery to reach their goal," Castelló said.

In addition to allowing a system designer to estimate the battery life the robots need to complete their task, the algorithms also enable the user to determine the amount of memory required to store the blockchain, the number of robots that will be needed, and the length of the path they can travel, even if a certain percentage of leader robots are hacked and become malicious.

"You can design your system with these tradeoffs in mind and make more informed decisions about what you want to do with the system you are going to deploy," he said.

In the future, Castelló hopes to build off this work to create new security systems for robots using transaction-based interactions. He sees it as a way to build trust between humans and groups of robots.

"When you turn these robot systems into public robot infrastructure, you expose them to malicious actors and failures," he said. "These techniques are useful to be able to validate, audit, and understand that the system is not going to go rogue. Even if certain members of the system are hacked, it is not going to make the infrastructure collapse." RR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A better way to develop spatial intelligence

Developing SLAM systems is resource intensive, technically challenging, and expensive. *In addition, the lack of common and shareable approaches for understanding the operational environment shared by robotics systems and humans has resulted in a multitude of system specific, spatial intelligence silos.*

■ Owen Nicholson • co-founder & CEO, SLAMcore

Today, the range of opportunities for robots and other autonomous machines is enormous. The COVID-19 pandemic has seen robots deployed for applications as diverse as UV cleaning of hospitals to last-mile delivery, for logistics and warehouse work, as well as for inspection services for off-shore wind farms. Robots are demonstrating increasingly sophisticated autonomous skills – especially in the crucial area of simultaneous location and mapping (SLAM), the process of building and updating a map of an operational environment, while simultaneously maintaining the location of a system within it.

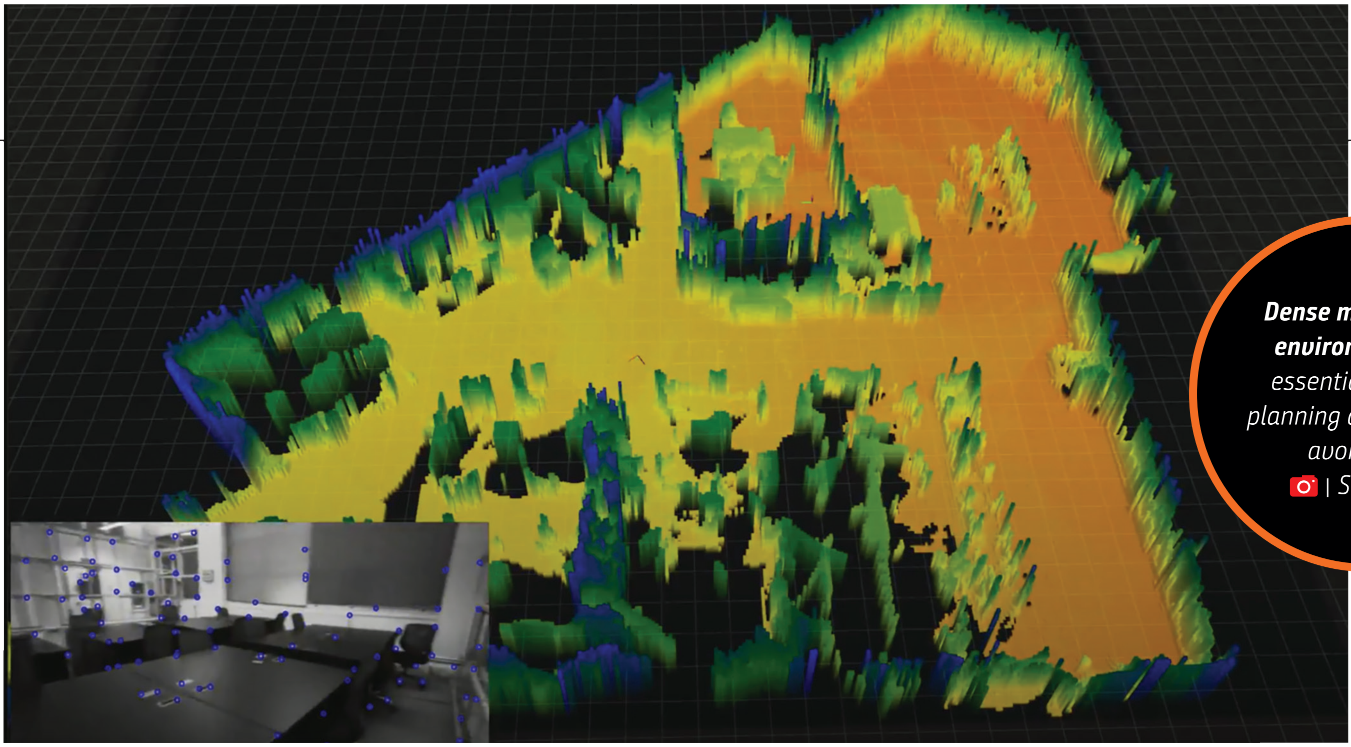
Where am I?

To operate effectively and safely in dynamic environments among people and other devices, robots must be able to calculate exactly where they are at all times. Using SLAM technologies and techniques, robots must be able to accurately, reliably and consistently answer the question ‘Where am I?’, without recourse to external systems like GPS or beacons and other way-point systems.

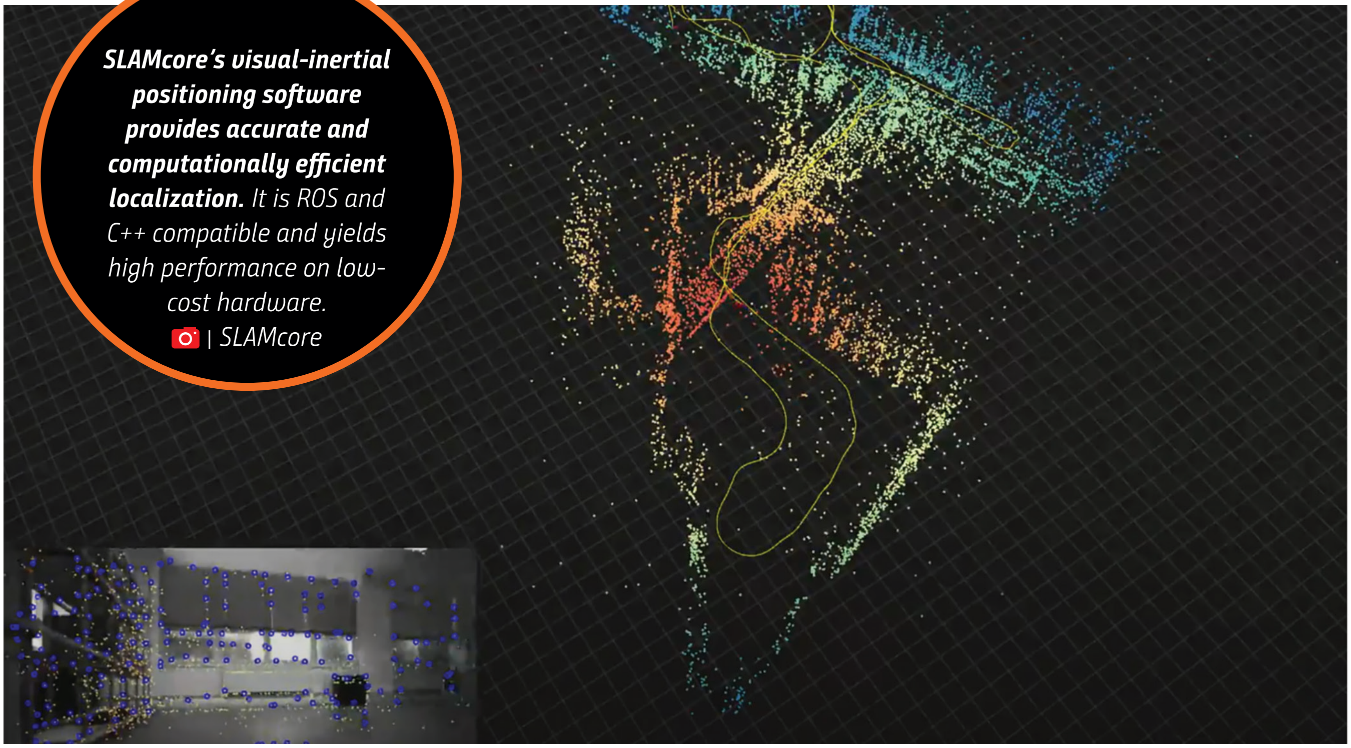
Bespoke Solutions

Many robotics firms are already creating robots that can determine their position with high levels of accuracy. But each ‘sees’ the world around it in its own way, and in a manner completely incomprehensible to other machines or humans. Hardware and software set-ups are tailored for specific use cases and operational environments, and the systems will fail if the systems are used in any way other than what they were precisely engineered for.

To illustrate, consider an automated cleaning robot and a hospitality robot working in the same shopping mall. The two robots perceive their operational environment around them completely differently. Each operates in a narrowly defined spatial silo engineered for



***Dense maps of the environment** are essential for path planning and obstacle avoidance.*
📷 | *SLAMcore*



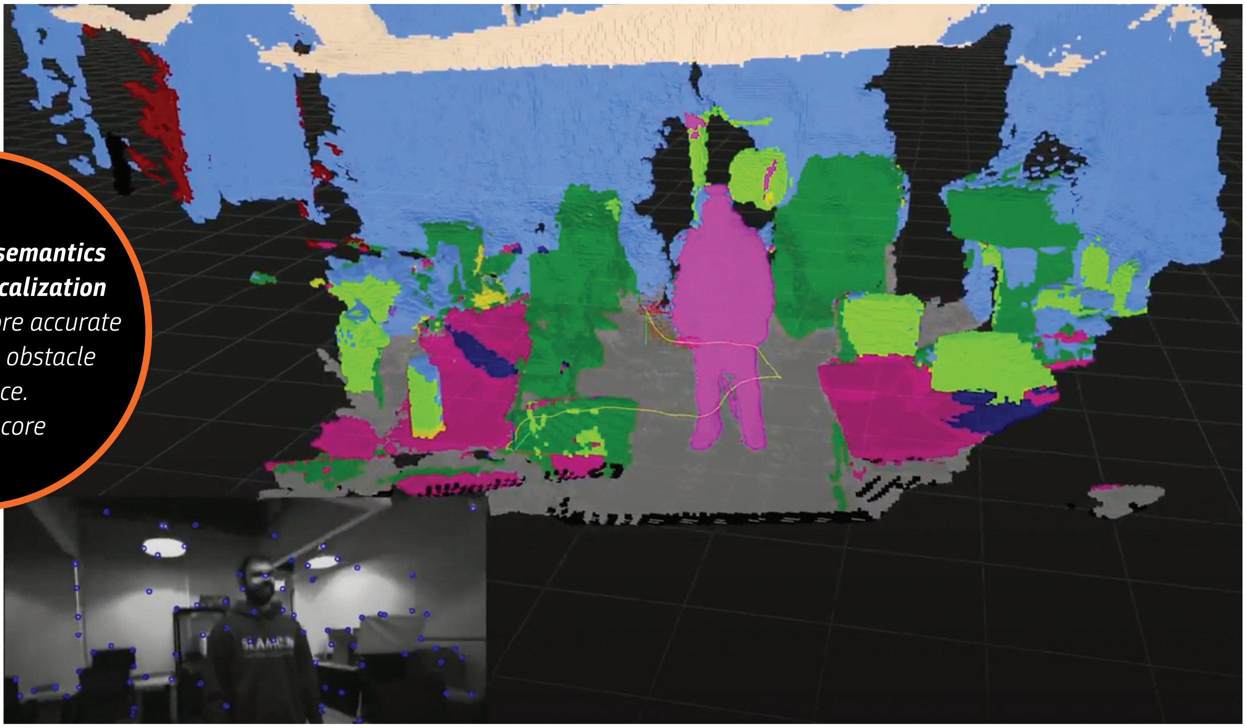
***SLAMcore's visual-inertial positioning software provides accurate and computationally efficient localization.** It is ROS and C++ compatible and yields high performance on low-cost hardware.*
📷 | *SLAMcore*

specific routes, functions and parameters. They are unable to collaborate with other robots, machines, or people.

The tight integration of sensors and SLAM software in each of the cleaning and hospitality robots means that mapping, localization and navigation information cannot be shared between them, and positioning-related algorithms cannot be reused in other systems. Without its own bespoke combination of sensors and software, each robot is unable to answer that core question: 'Where am I?'

Missed opportunities

Developing SLAM systems is resource intensive, technically challenging and expensive. In addition, the lack of common and shareable approaches for understanding the physical space around autonomous devices has resulted in a multitude of system specific, spatial intelligence silos. This robotics Tower of Babel threatens the projected growth and viability of the robotics industry, and inhibits the development of robots that could address some of the most pressing challenges in the economy, the environment and society.



***Deep learning semantics can enhance localization and maps** for more accurate path planning, obstacle avoidance.*

📷 | *SLAMcore*

Reinvention quagmire

Hundreds of innovative, entrepreneurial companies are desperate to deploy their proof-of-concept designs in the real world. These are the next generation of businesses that will drive the growth and increase the value of the robotics market.

Many of these firms have brilliant designs and applications that could literally change the world. But many are stuck reinventing the core technology of spatial intelligence. Each pursues their own approach, establishing new silos, and then struggling to adapt to the thousands of 'edge-cases' that cause their designs to fail in unexpected ways.

For both start-ups and larger established players, what is required for robotics systems to reach their full potential is access to a common, shared approach for mapping, positioning and understanding their operational environment.

Multiple designs, one approach

There is no one-size fits all for robotics systems. They each have their own form factor, hardware/software setup, and parameters tailored to meet specific requirements. But there can be a consistent and repeatable way of perceiving the world around these devices. Nature provides a clue.

There are thousands of different 'designs' for living creatures on Earth, but a surprisingly consistent way lifeforms position themselves in the world around them. This approach, honed through millions of years of evolution, emphasizes a combination of two eyes and inertial sensors in the inner ear to calculate position.

At SLAMcore, we have mirrored nature by creating a common approach to SLAM using two cameras and an inertial measurement unit (IMU). With these core components, SLAMcore is creating a universal language of spatial intelligence that can benefit all robot developers. Simple, effective and widely available sensors, combined with SLAMcore algorithm, provides a consistent, repeatable and shareable way for any robot to perceive, map and describe the world around it.

Vision is key

Even basic, low-cost standard-definition cameras capture huge amounts of data. Processed in the right way, this information can support instant and accurate calculations of position – even with no prior knowledge of the location or physical situation.

The algorithms developed by SLAMcore engineers are able to take visual data to create sparse point-clouds of the 'features' in any scene that a robot or autonomous device can use to accurately and robustly calculate its position. The same data is also used to create detailed 2.5D and 3D maps that add more functionality, including identification of free space that is safe to occupy. Additionally, the software identifies and labels all the objects in a scene attaching semantic understanding of 'what' the robot is seeing. This information is the basis for decisions on how it should react to objects in its environment.

A common language

Using vision as the primary input for mapping, localization, and navigation creates a common framework – a language of spatial intelligence that can be shared with other devices, and with humans. If robots of all types, and the humans that work with and around them, all 'see' physical space in the same way, it is much easier to begin to collaborate, share and build a common understanding.

Using a common language to describe the world around robots also means that information can be aggregated and shared. As such, it can unleash a new wave of growth in the robotics sector. Customers benefit not only from a shared language for spatial intelligence that will short-cut their own development cycles, but it also provides a constantly growing knowledge base.

Constant evolution

Although robots and autonomous devices come in many different shapes and sizes, they tend to fail in common ways. Outside of the lab, robots quickly encounter unexpected situations – unforeseen objects, different lighting conditions, new layouts or physical environments. These edge cases are difficult to anticipate, simulate and program for, and they are usually the source of robot failure in the real world. By describing these unexpected situations in a common way – using data from cameras and IMUs processed consistently by SLAM algorithms – every edge case, and its solution, can be recorded and shared.

Just as children learn through trial-and-error, robots, too, can 'learn' from their failures, as well as the failures of other robotics systems. In terms of positioning, sharing data and reusable maps allows knowledge about a physical environment to persist so that robots can learn from experiences of other robotic systems.

Virtuous circle

By analyzing data from hundreds of previous positioning edge cases, SLAMcore engineers have identified how and why SLAM estimations have failed in the past, and how they can be overcome. They have also developed a consistent frame of reference that allows them to leverage and contribute to a global body of data on how robots locate and map in real-world situations.

As data granularity and scale increases, and more edge case solutions are found, SLAM algorithms are tweaked to make better positioning 'judgement calls.' As mapping techniques improve, so do robot operations, allowing robotics systems to be used more widely, resulting in the collection of even greater amounts of edge-case data. This process creates a virtuous circle that benefits all participants.

Shared maps

Constantly updated, shared maps have immediate and obvious applications for wide scale robotics deployments. Fleets of robots can contribute to shared maps so that every change is noticed and passed on to all those affected. Robots learn from their peers' experiences, and maps can be shared with humans so that both they and the robots have a commonly agreed map that accurately represents their shared operational space, and can be verified with the world around them.

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Digital twins

The accuracy, currency and robustness of these maps, constantly updated as every robot surveys a scene, become the foundation for a real-time digital twin of the physical world. This provides many benefits for those managing facilities, locations or properties, providing real-time data on the exact state of the physical world, but also the opportunity to test and simulate actions before implementing them.

As a universal language of spatial intelligence, digital twins will unleash a wave of robotic innovation and deployment, delivering significant benefits across industrial, commercial and consumer sectors. The value and the utility of a hyper-accurate, real-time digital twin of the physical world, automatically updated and shared as every robot or autonomous device passes through an operational environment, is immense.

Common language

We have developed a common language for spatial intelligence that allows developers and designers to learn from the errors of others, enabling them to progress further, faster. With tens of thousands of sessions, thousands of hours of operation, and well over three million meters traveled and recorded by our customers, this common language has incorporated deeper knowledge, across a wider range of scenarios, than any individual engineer can hope to master. Moreover, an event or failure experienced by one class of robotics systems (say, a drone designed for delivery), can provide valuable information to a designer of another type of system (a wheeled robot for hospitality, for example).

Tower of Babel

The story of the Tower of Babel was a warning to humankind not to attempt to reach the heavens. But in contrast to the humans in the origin myth, we want robots to share and benefit from a common language, one with which to describe the physical environment around them. We want robots to cooperate with each other, and to work alongside humans to find solutions to some of the world's most pressing challenges. We want, and many would argue, need, robots to help build a better world.

At SLAMcore, this is the mission that drives us -- to make quality spatial intelligence accessible to all. If robots and other intelligent systems use a consistent language for shared spatial intelligence, we can democratize access to robust, accurate and fast SLAM. This would open up many opportunities and create the necessary building blocks for an explosion of robotics solutions to address critical challenges such as climate change, pandemic and disaster response, care for the elderly and disabled, as well as providing cost effective and efficient ways to deliver the economics of abundance. RR

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ActiNav enables lights-out machine tending at family-owned manufacturer

***To address labor shortages and long cycle times,** New England Union Company deployed a UR10e cobot arm and ActiNav bin picking system from Universal Robots to run untended all night long.*

■ *The Robot Report Staff*

New England Union Company (NEU) is a family-owned foundry and machine shop that makes brass threaded pipe fittings for the plumbing and shipping industries. NEU replaced outdated equipment with modern CNC machines, but manufacturing staffing remained a challenge in Rhode Island.

To address labor shortages and long cycle times, the company deployed a UR10e cobot and ActiNav bin picking system from Universal Robots (UR) to run untended all night long. With ActiNav, NEU can increase output with the same number of employees.

Challenge

Updating the shop from older lathes to modern CNC machines improved product quality, but also increased cycle times. This impacted deliveries and didn't effectively use valuable machinists. NEU needed to increase output without adding manned shifts, and wanted to automate less-specialized tasks so that employees could be moved to higher-value roles such as setting up CNC machines and spending more time on inspection and quality.

Solution

NEU's first collaborative automation project used a UR10e cobot and its built-in palletizing function to pick parts from an organized tray to feed a gantry system for the CNC machine that performs threading, drilling, and other operations. The UR10e cobot arm can lift up to 27.6 lb (12.5 kg) with a maximum reach of 51.1 inches (1300 mm).

It took an employee about an hour to load the ordered grid on the tray, and the cobot could run for about 8 hours unmanned. But the company needed a system that could run all night without an operator. NEU vice president Brent Petit explored vibratory systems, but they couldn't meet NEU's repeatability requirements. That's when he was introduced to ActiNav.

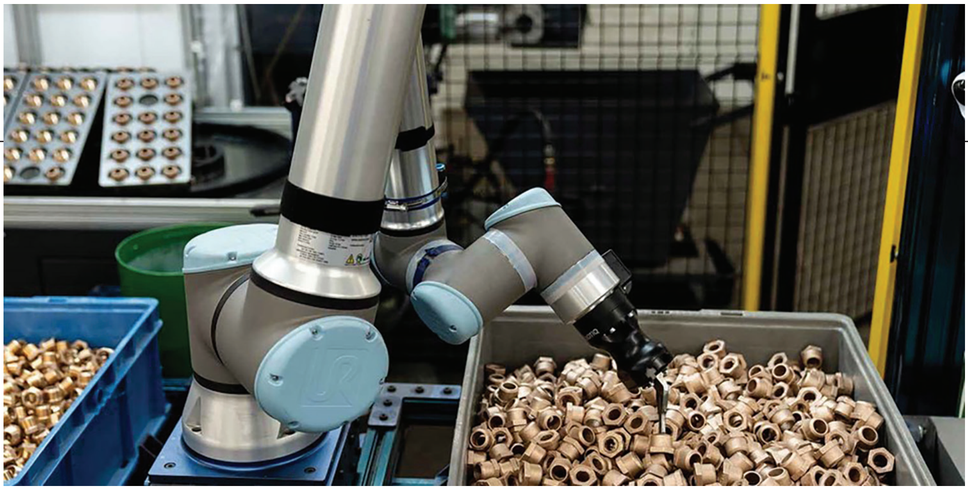
"The advantages of the ActiNav system is that we can just bring a bin right over to the machine, set it up, and it will start picking right from the bin," said Petit. "We don't need to have an employee standing there, picking up the parts and placing them into that pallet system that we were doing beforehand."

UR won a 2021 RBR50 Robotics Innovation Award for its ActiNav system. The "plug-and-produce" UR+ application kit makes it easier to deploy cobots for common applications. ActiNav requires a UR5e or UR10e cobot, an end effector of the user's choice, and an application-specific frame or fixture. The kit includes the ActiNav software and autonomous motion module controller, the URCap user interface software, along with a choice of 3D sensors. The ActiNav system can handle vision processing, collision-free motion planning, and autonomous real-time robot control.

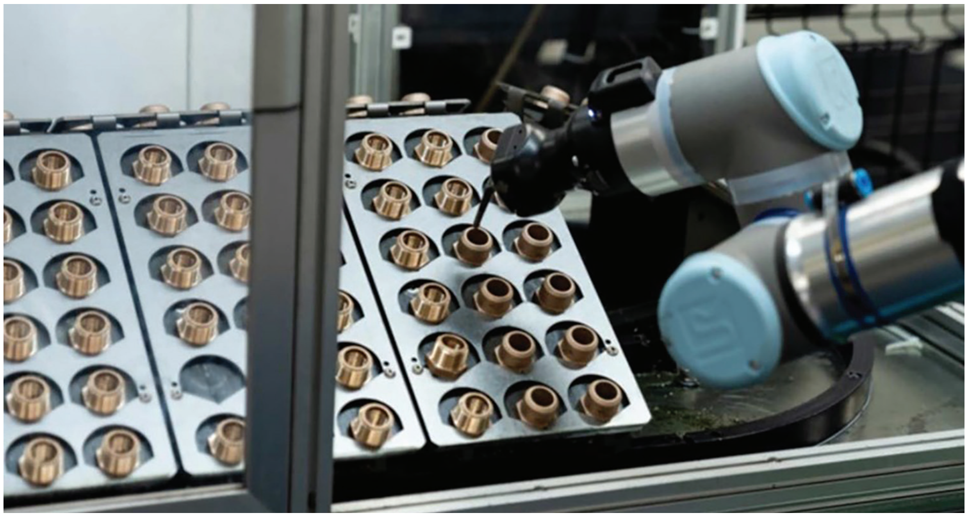
Autonomous bin picking is a common robotics application, but it is rarely, if ever, referred to as "easy to use." Deploying autonomous bin picking systems usually requires integration and programming efforts customers can't do themselves. ActiNav changed that as it doesn't require programming expertise to deploy. ActiNav uses a teach-by-demonstration approach via a wizard-guided setup process on the cobot's teach pendant. UR claims the system can be deployed in less than two hours.

Results

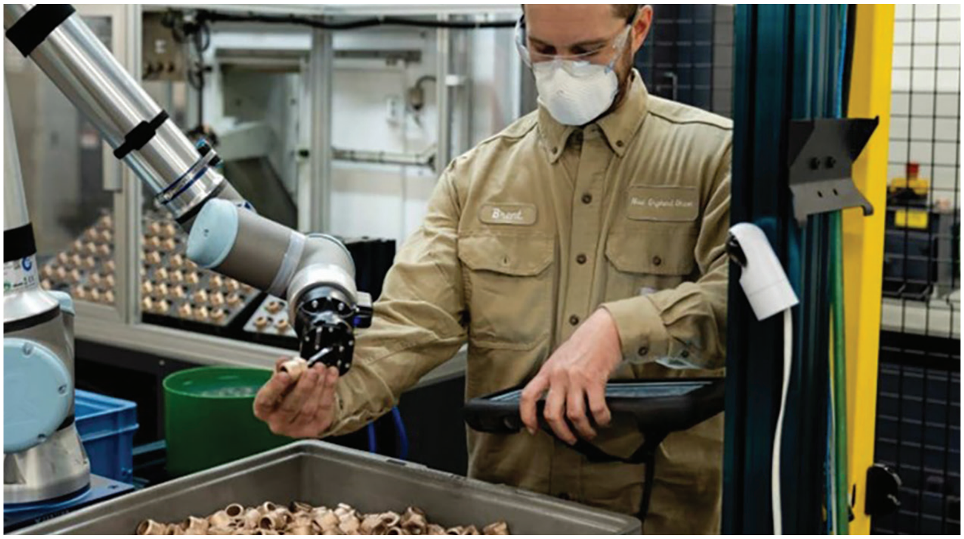
During day shifts, employees can quickly refill the bin as needed, then return to other tasks. At the end of the day, workers simply bring a full bin to the ActiNav system, check the standard, set it to run, and leave for the night. The bin holds enough parts to keep the robot and CNC machine running unmanned all



***This ActiNav system with a UR10e cobot autonomously picks parts from a deep bin** to load a gantry system that is the staging for a CNC machine for further operations such as threading or drilling.* 📷 | *Universal Robots*



***The UR10e cobot uses a Robotiq Hand-E gripper to place oriented parts onto gantry systems.** The Hand-E gripper does both internal and external picks.* 📷 | *Universal Robots*



***Teaching ActiNav involves downloading a step file into the cobot's teach pendant,** scanning the parts and setting clearance shapes, then teaching pick and place rules for the gantry system and regrip fixture.* 📷 | *Universal Robots*

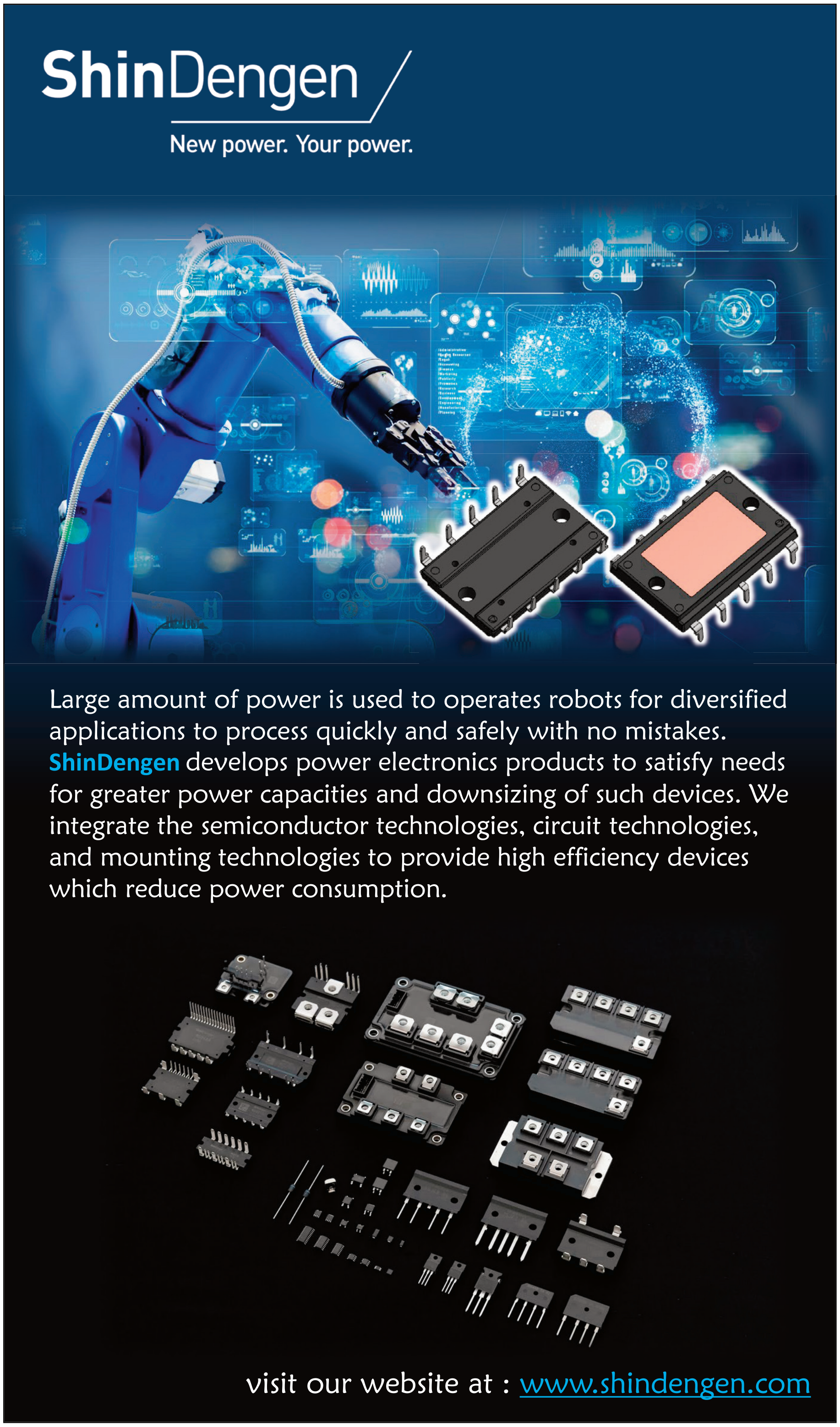
Case Study Breakdown	
Company	New England Union Company
Location	West Warwick, R.I.
Industry	Manufacturing
Challenges	Labor shortage, long cycle times
Partner	Universal Robots
Robot	ActiNav machine loading system with UR10e cobot
Gripper	Robotiq Hand-E
Task	Machine tending
Results	Increased output and production hours, addressed labor shortage

night long, and employees return in the morning to bins of finished products. They inspect the last part off the machine and take the finished bin to inventory, refill the raw parts bin, and let the robot keep running.

The ActiNav system first performs a 3D scan of the bin then the UR-10e cobot, using a Robotiq Hand-E gripper, picks a raw part and places it onto a regrip fixture. The UR robot activates the fixture to vibrate the part so it's perfectly lined up to load into the gantry system that is the staging system for the CNC machine. At a signal from the machine, the robot picks a finished part from the gantry system, dunks it in water to rinse off the coolant, and drops the part into a finish pan. Then the robot returns to the regrip fixture to pick the correctly oriented raw part and places it onto the gantry system to go into the CNC machine before starting the cycle again.

NEU is currently running 10 different parts on the ActiNav system, with the goal of running more than 30 different parts. ActiNav will run 24 hours a day, five days a week, allowing NEU to increase output to meet demand, with the same number of employees.

"The ActiNav system has a big bin with enough parts that fit in that bin where we don't have to worry about it stopping," said Andrew Lieffers, operations manager, NEU. "It can run all through the night. We come back to finished parts, and it's a beautiful thing." **RR**



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What to consider when choosing rotary encoders

Rotary encoders play a critical role in robot design and production. *They must be matched to the given space, cabling, sensors, precision, and tolerances. Installation should be efficient. Find out what to consider.*

The Robot Report Staff

Controlled servo drives are used in many areas of automation technology, including robotics. The selection of a rotary encoder, or encoder technology, for use within the system depends on the accuracy requirements of the application and whether the application will use position control, velocity control, or both.

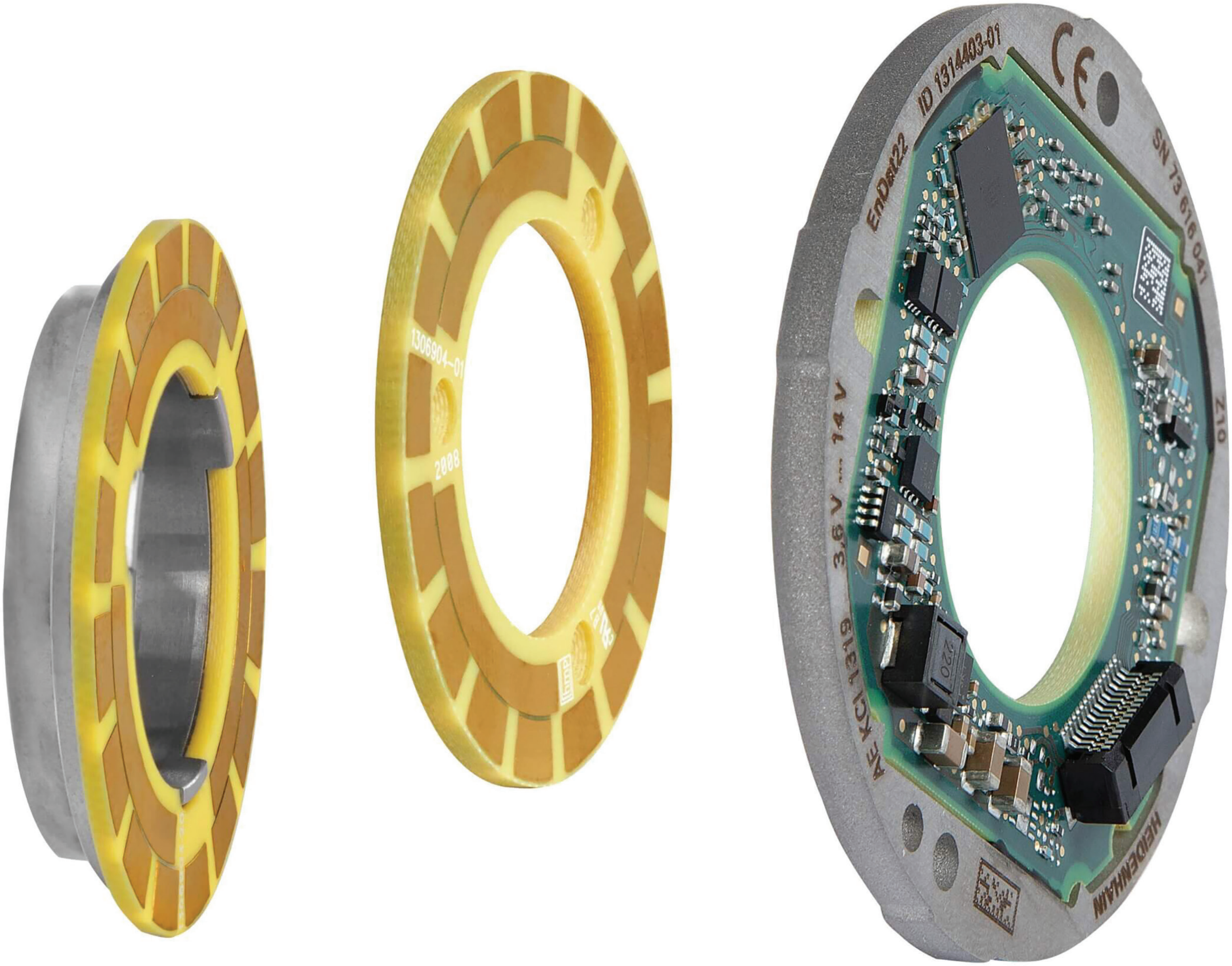
Before making an encoder decision, engineers should examine this and all the major encoder properties that have the largest influence on important motor performance. These include:

- Positioning accuracy
- Speed stability
- Audible noise
- Power loss
- Bandwidth, which determines drive command-signal response

Positioning accuracy

Positioning accuracy depends solely on the application requirements. Resolvers, for example, mostly have one signal period per revolution. Therefore position resolution is extremely limited and accuracy is typically in the range of ±500 arcsec. Assuming interpolation in the drive electronics, this usually results in a total of 16,384 positions per revolution.

On the other hand, an inductive scanning system — as found in many rotary encoders — will provide significantly higher resolution, typically in the range of 32 signal periods per revolution, resulting in an accuracy in the range of ±280 arcsec. The interpolation in this case is internal to the encoder, resulting in 131,072 positions per revolution.



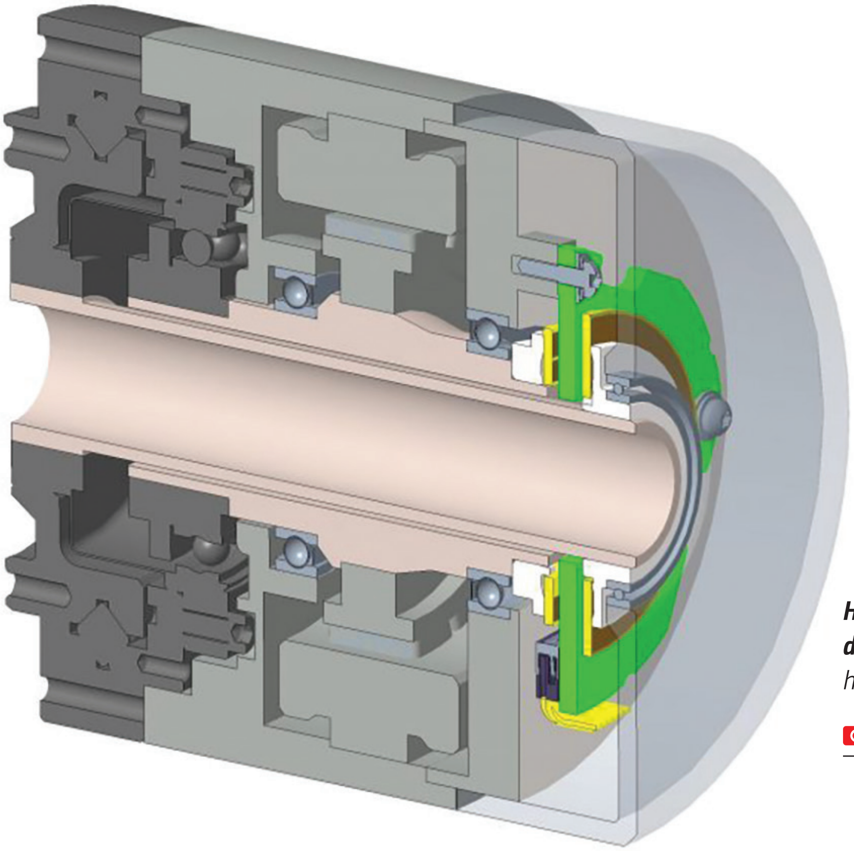
To ensure smooth drive performance, *an encoder must provide a large number of measuring steps per revolution.* | *Heidenhain*

Optical rotary encoders are based on very fine graduations, commonly with 2048 signal periods per revolution, and therefore, even higher resolutions are possible with internal interpolation electronics. The output resolution here is 25 bits, which means 33,554,432 absolute positions per revolution with accuracies in the range of ±20 arcsec.

Speed stability

To ensure smooth drive performance, an encoder must provide a large number of measuring steps per revolution as the first piece of the puzzle. However, engineers must also pay attention to the quality of the encoder signals. In order to achieve the high resolution required, the scanning signals must be interpolated. Inadequate scanning, contamination of the measuring standard, and insufficient signal conditioning can lead to the signals deviating from the ideal shape. During interpolation, errors can occur whose periodic cycle is within one signal period. Therefore, these position errors within one signal period are also referred to as “interpolation errors.” With high-quality encoders, these errors are typically 1 to 2 percent of the signal period.

The interpolation error adversely affects the positioning accuracy and significantly degrades the speed stability



Higher resolutions and accuracies also reduce disturbances in the motor current *in the way of heat generation and power loss.*

| Heidenhain

and audible noise behavior of the drive. The speed controller calculates the nominal currents used to brake or accelerate the drive depending on the error curve. At low feed rates, the feed drive lags the interpolation error. At increasing speeds, the frequency of the interpolation error also increases. Since the motor can only follow the error within the control bandwidth, its effect on the speed stability behavior decreases as speed increases. However, the disturbances in the motor current continue to increase, which leads to disturbing noises in the drive at high control loop gains.

Higher resolutions and accuracies also reduce disturbances in the motor current in the way of heat generation and power loss.

Bandwidth

Bandwidth (relative to command response and control reliability) can be limited by the rigidity of the coupling between the motor shaft and encoder shaft as well as by the natural frequency of the coupling. Encoders are qualified to operate within a specified acceleration range. Values typically range from 55 to 2,000 Hz. However, if the application or poor mounting cause long-lasting resonant vibration, it will limit performance and possibly damage the encoder.

Natural frequencies vary depending on the stator coupling design. This frequency needs to be as high as possible for optimal performance. The key is to ensure that the bearing of the encoder and the bearing of the motor are as close to perfect alignment as possible.

This mechanical configuration will result in a holding torque approximately four times greater than a standard hollow shaft encoder with a 2-mounting tab stator coupling. This will increase the bearing life of the encoder and provide exceptional natural frequency and acceleration properties. Additionally, this configuration will virtually eliminate any limits on the bandwidth of the drive!

In summary, many factors influence the selection of an appropriate rotary encoder for use in controlled servo drives. And while positioning accuracy requirements are paramount in the consideration process, it is important to know how other properties — such as speed stability, noise, possible power loss, and bandwidth — will influence the application. A good fit from the start will provide positive performance in the motor/drive system in the end. **RR**

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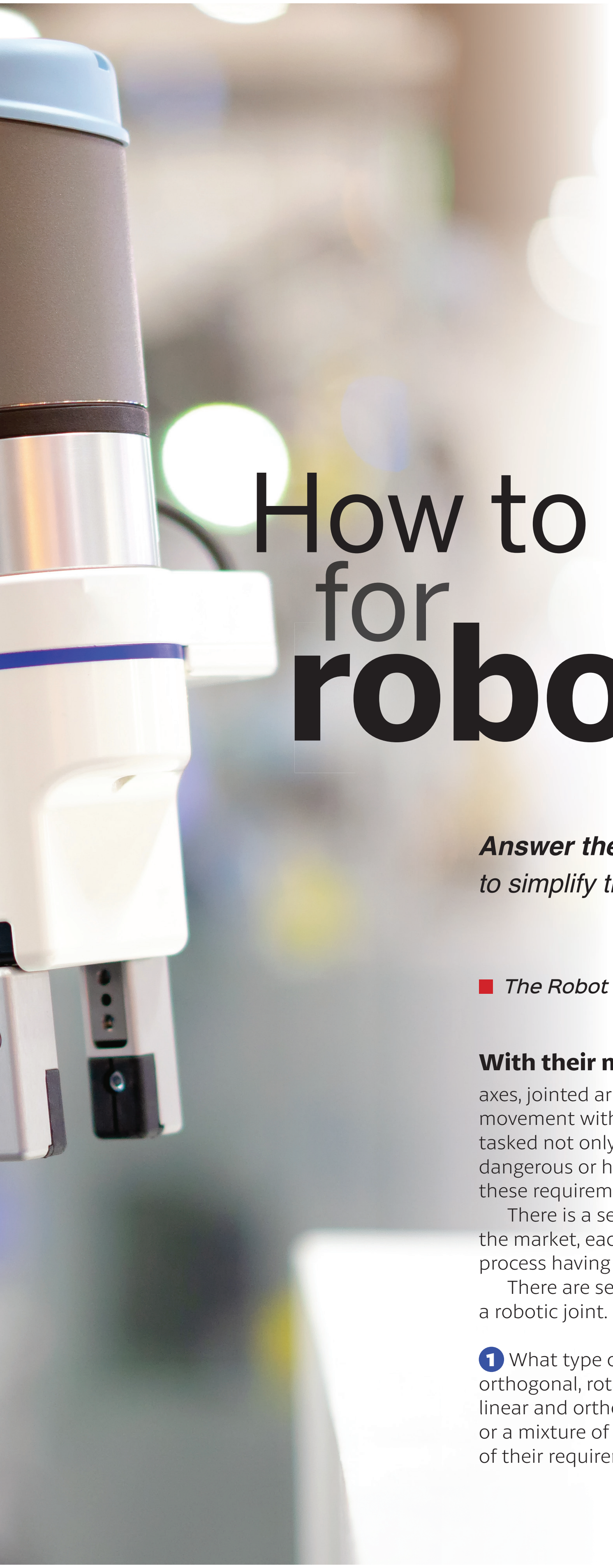

How to select motors for robotic joints

***Answer these questions before** going into the selection process to simplify the search.*

The Robot Report Staff

With their many parts and the need to be able to smoothly rotate all of their axes, jointed arm robots require the perfect actuator to power their specialized movement with the right type and amount of force. Robots with jointed arms are often tasked not only with mundane tasks, but also with performing human-like actions in dangerous or high-stakes environments, so the motor must be perfectly matched to these requirements.

There is a seemingly endless selection of DC, stepper, and servo motor products on the market, each with their own advantages and drawbacks. Going into the selection process having answered a few key questions will vastly simplify the selection process.

There are several factors to consider when selecting a motor to power a robot with a robotic joint.

① What type of robotic joints are used? There are five types of robotic joint: linear, orthogonal, rotational, twisting, and revolving. Does your application use the simpler linear and orthogonal joints, the more dynamic rotational, twisting, or revolving joints, or a mixture of both? This will determine the types of motions and the related nuances of their requirements.

② How much noise is tolerable in the application? If your application will be used in a factory largely away from people, noise may not be an issue. But if it will be used alongside humans for more than a brief amount of time, you may favor a quieter motor.

③ How much precision is required? When a robot is being used to move shelves in a warehouse, not much precision is required, whereas there is no room for error when one is filling prescriptions. Different motors provide precision in different ways, some with distinct disadvantages; it's important to know which of these may be allowable for your product.

④ How much torque is necessary? Torque can be achieved at various speeds and with varying degrees of constancy. If you need high torque only at a particular speed, you may be able to sacrifice unnecessary torque capability for other motor features.

Now let's review the three types of electric motors most often used to run applications on a typical jointed arm robot—DC, stepper, and servo—against these considerations.

DC motors

DC motors come in brushed and brushless varieties. It is commonly thought that brushless DC motors have supplanted brushed ones, but brushed DC motors are still quite popular for some applications. A brushed DC motor is about 75%–80% efficient, achieves high torque at low speeds, and is simple to control, but creates quite a bit of noise due to the brushes used to rotate the machinery. On the other hand, a brushless DC motor is quieter, even more efficient, and can maintain continuous maximum torque, but is more difficult to control and can sometimes require a specialized regulator. Although DC motors usually provide low torque, they can achieve high speeds and are good for washing machines, fans, drills, and other machines that require constant circular motion.

There is always the option of adding a gearbox to the system to create more torque for robotic applications utilizing a robotic joint mechanism. Keep in mind, the motor and gearbox should be designed to work together, so purchasing a motor with an integrated gearhead is a good idea in this case.

Stepper motors

Stepper motors can control precise movement, have maximum torque at low speeds, and are easy to control, making them popular in process automation and some other robotics. However, they come with several drawbacks: They are noisy and relatively inefficient, and they run hot since they continuously draw maximum current. Finally, since they have low top speeds, they are known to skip steps at high loads, which can be a critical flaw in some jointed arm applications. Despite these limitations, they have proven effective in medical imaging machines, 3D printers, and security cameras.

Servo motors

Servo motors provide extremely precise movement, thanks to a feedback loop that senses and corrects discrepancies between actual and target speed. They can provide high torque at high speeds, and can even handle dynamic load changes. Additionally, servo motors are lightweight and efficient. Downsides of using servo motors include their possibility for jitter as they respond to feedback and their requirement for sophisticated control logic. Despite these drawbacks, the precision offered by servo motors often make them a good option for a jointed arm robot, the sophisticated movement of which is designed to match that of humans!

Your jointed arm robot may perform sensitive tasks and come with high expectations, so you need a motor that not only powers your system but makes your robot maximally appropriate for the environment in which it operates. When selecting a motor, making sure you know exactly what you're trying to achieve and ranking your priorities will help you make smart functionality tradeoffs for optimal performance and suitability. RR

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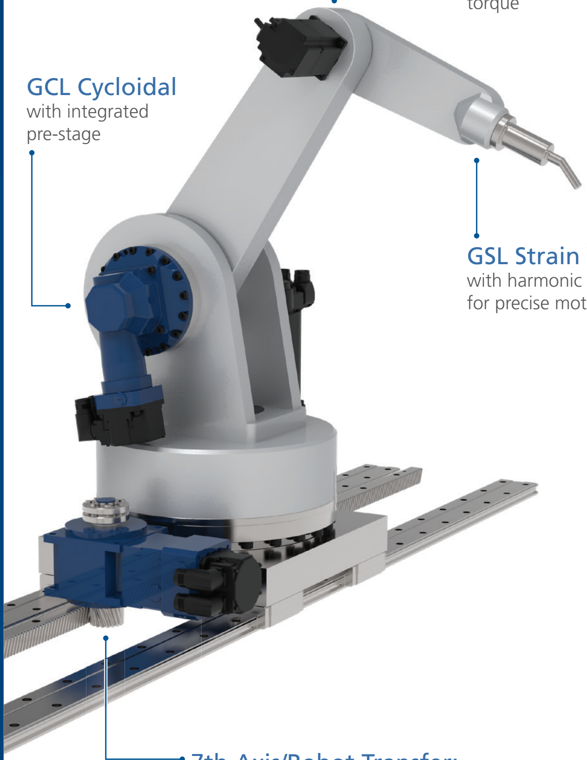

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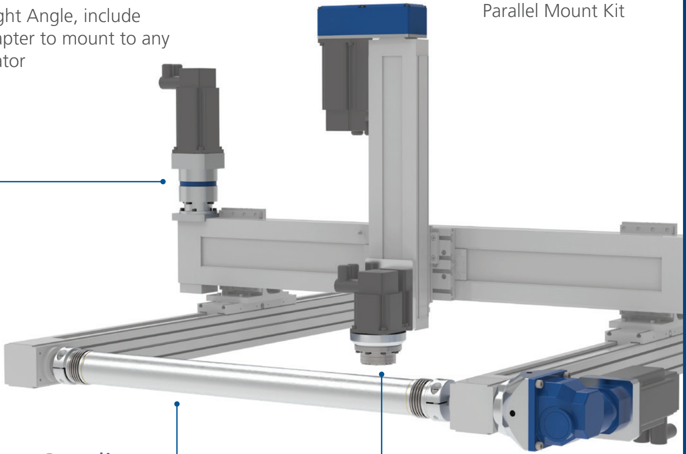

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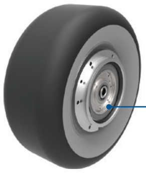

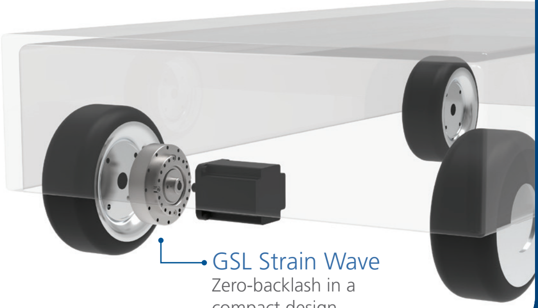

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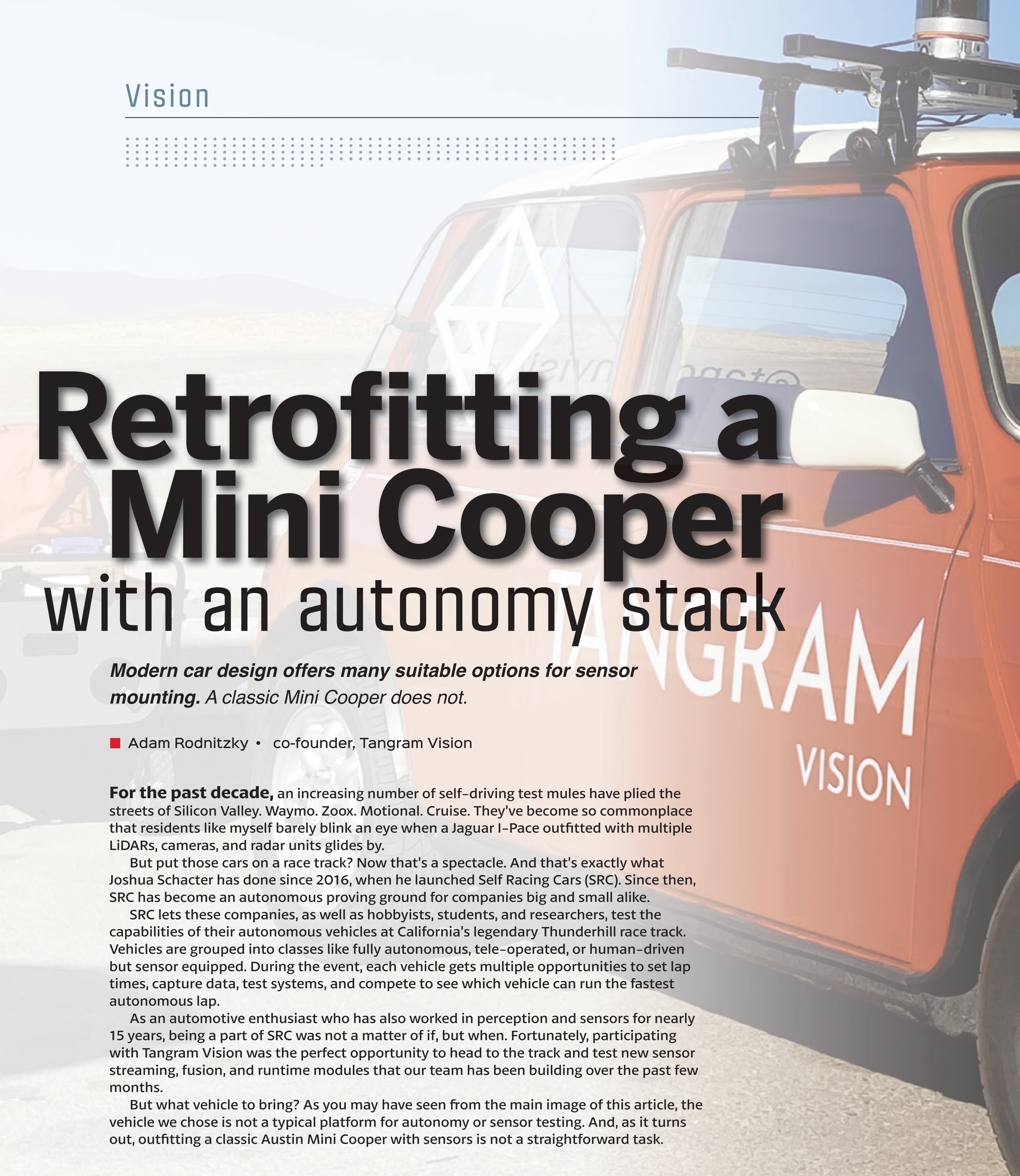

Retrofitting a Mini Cooper

with an autonomy stack

***Modern car design offers many suitable options for sensor mounting.** A classic Mini Cooper does not.*

Adam Rodnitzky • co-founder, Tangram Vision

For the past decade, an increasing number of self-driving test mules have plied the streets of Silicon Valley. Waymo. Zoox. Motional. Cruise. They've become so commonplace that residents like myself barely blink an eye when a Jaguar I-Pace outfitted with multiple LiDARs, cameras, and radar units glides by.

But put those cars on a race track? Now that's a spectacle. And that's exactly what Joshua Schacter has done since 2016, when he launched Self Racing Cars (SRC). Since then, SRC has become an autonomous proving ground for companies big and small alike.

SRC lets these companies, as well as hobbyists, students, and researchers, test the capabilities of their autonomous vehicles at California's legendary Thunderhill race track. Vehicles are grouped into classes like fully autonomous, tele-operated, or human-driven but sensor equipped. During the event, each vehicle gets multiple opportunities to set lap times, capture data, test systems, and compete to see which vehicle can run the fastest autonomous lap.

As an automotive enthusiast who has also worked in perception and sensors for nearly 15 years, being a part of SRC was not a matter of if, but when. Fortunately, participating with Tangram Vision was the perfect opportunity to head to the track and test new sensor streaming, fusion, and runtime modules that our team has been building over the past few months.

But what vehicle to bring? As you may have seen from the main image of this article, the vehicle we chose is not a typical platform for autonomy or sensor testing. And, as it turns out, outfitting a classic Austin Mini Cooper with sensors is not a straightforward task.

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***Tangram Vision's sensor-equipped classic Mini Cooper** at Self Racing Cars 2021.*
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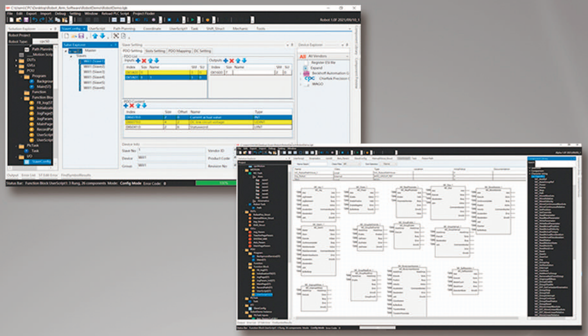

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Mechanical mounting

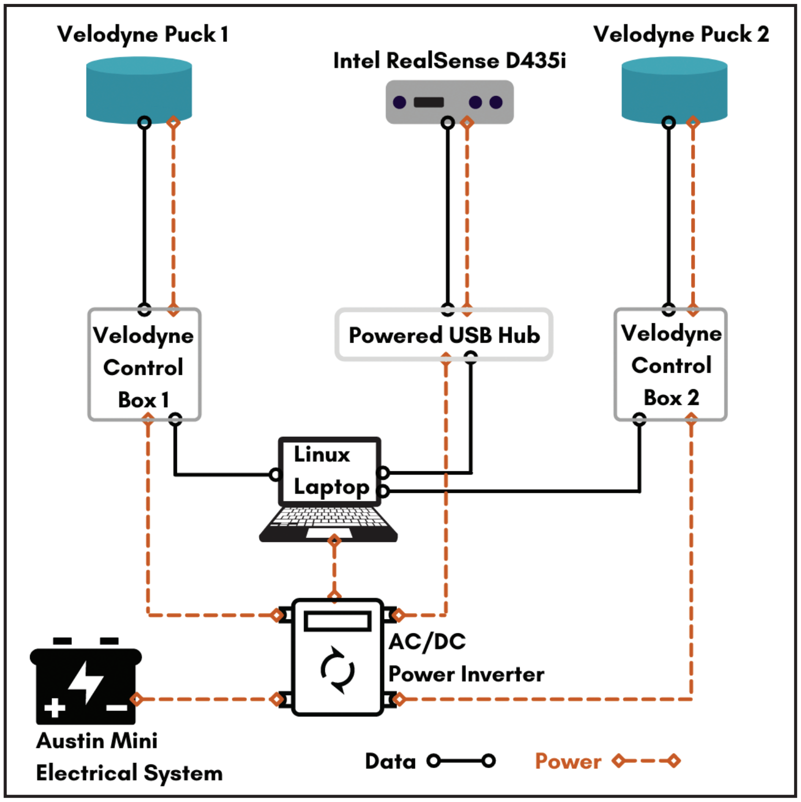
One of the first challenges we tackled was determining where the sensors could go, and how they would be mounted to the Mini. Given its 1950s origins, the Mini was clearly not designed with sensors in mind, much less many other items we take for granted on modern cars, like … safety equipment. In a classic Mini, you are the bumper.

Modern car design offers many suitable options for sensor mounting. They feature rigidly mounted side mirrors, which can be used as a stable platform to attach a sensor. They often have flat roofs upon which a sensor can be easily mounted. Flat windshield and rear window glass allows for quick internal mounting of cameras. A classic Mini has none of these features. With the exception of the door skins and side window glass, everything is curved, which complicates the task of finding stable, flat mounting surfaces for sensors. Therefore, we turned to a solution that many other autonomous vehicle developers have chosen for prototyping: a roof rack.

Given that the classic Mini has been out of production for 21 years, there are no bespoke racks being produced for it. Fortunately, the Mini's 1950s design has equipped it with prominent rain gutters on the roof, which is similar in design to what you find on a modern Jeep Wrangler. This is exactly the rack we found that we could adapt to the classic Mini.

Having sourced an appropriate rack, our remaining mechanical mounting needs were solved by multiple trips to a local Home Depot. We built a flat, rigid platform for the sensors with 16-gauge steel panels that we bolted directly to the rack cross bars. Our chosen sensors (two Velodyne Pucks and an Intel RealSense D435i) all included a threaded insert for tripod mounting, which used standard 1/4"-20 threads. We were able to easily attach all of the sensors using 1/4"-20 bolts upthreaded through the metal platform.

We needed to raise our LiDAR units further off the roof to ensure they would be able to capture sufficient data in 360



Component, power, and data diagram *for the Mini Cooper sensor array.* | *Tangram Vision*

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degrees around the Mini. It turns out that the 4" footprint of the Velodyne Puck units is a perfect fit on an electrical junction box, which is what we used. As a directional sensor, the Intel RealSense D435i simply needed to mount at the front of our sensor platform. An upside down 1/4"-20 bolt at the front of the rack did the trick. To keep vibration to a minimum, all sensors were isolated from the metal rack with a red rubber packing gasket. With the three sensors securely mounted in their proper positions, our next step was to route cabling for power and data.

Transmissions of data and power

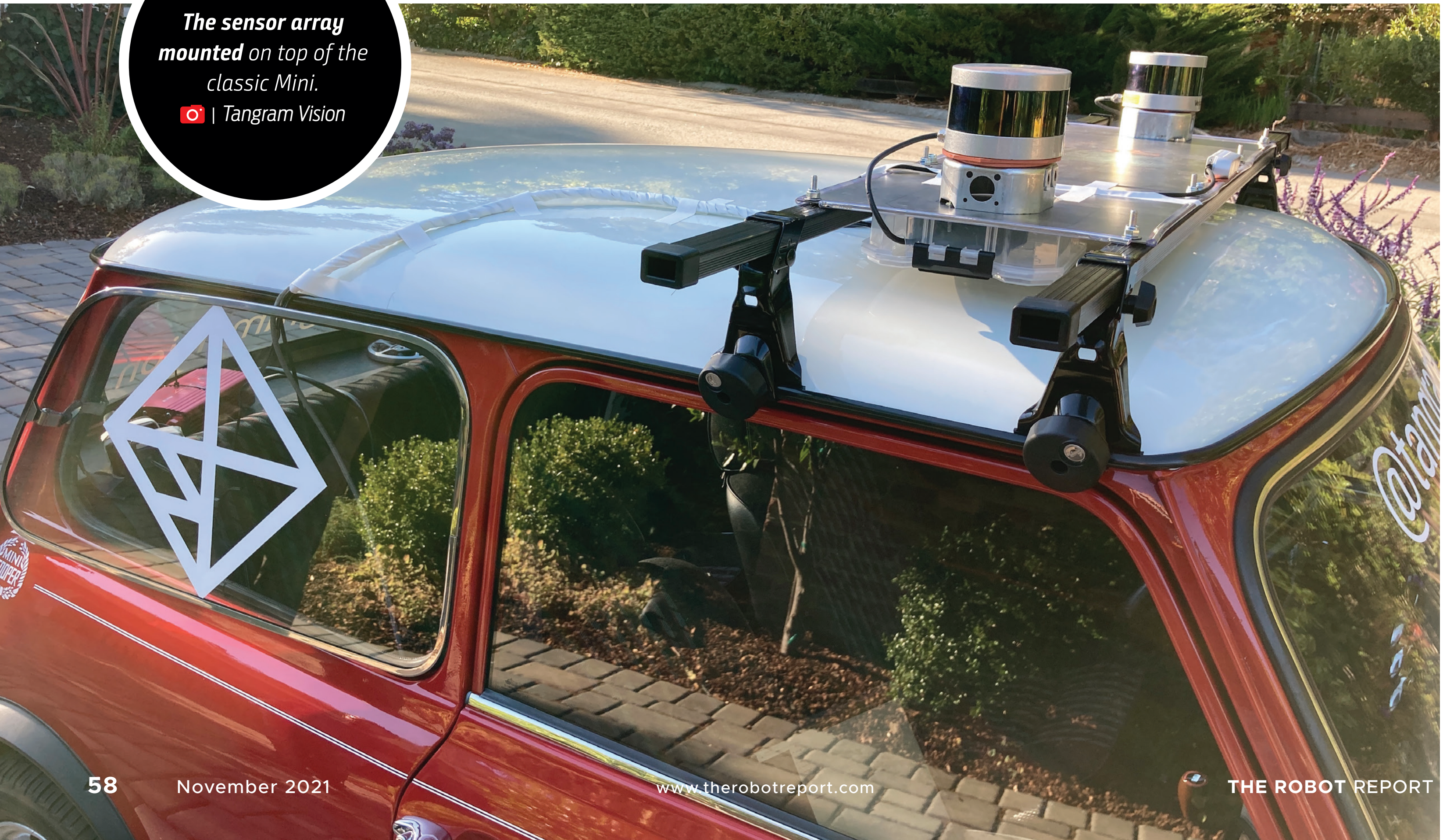
Both the Velodyne and RealSense units require an AC power source, which meant installing an AC/DC inverter in the Mini. Our first concern was whether the Mini's electrical system would even be up to the task of powering the inverter, as it would need to power the three sensors, a USB hub, and a laptop PC. After all, the Mini's electrical system used Lucas components. Lucas is affectionately known as the "Prince of Darkness" among British auto enthusiasts due to the manufacturer's reputation for spotty quality and sudden component failures. Fortunately, the Mini's electrical system did just fine, powering all components reliably through the event.

With power solved, the last challenge was data cabling from the sensors to a compute source. The Intel RealSense uses a single USB-C port for both power and data, hence the powered USB hub. This also meant sourcing a USB cable that could transmit both power and data at a high enough rate over a long length, as the cable that came with the RealSense was not long enough to reach from the center of the Mini's roof to the USB hub in the interior. The Velodyne sensors split power and data into two, with the latter achieved via Cat6 Ethernet, with no practical limits on cable length. With our sensor rig mounted, powered, and transmitting data, the final step was capturing and processing the data it generated, while hurtling around Thunderhill at high speed.

Software testing for the Tangram Vision SDK

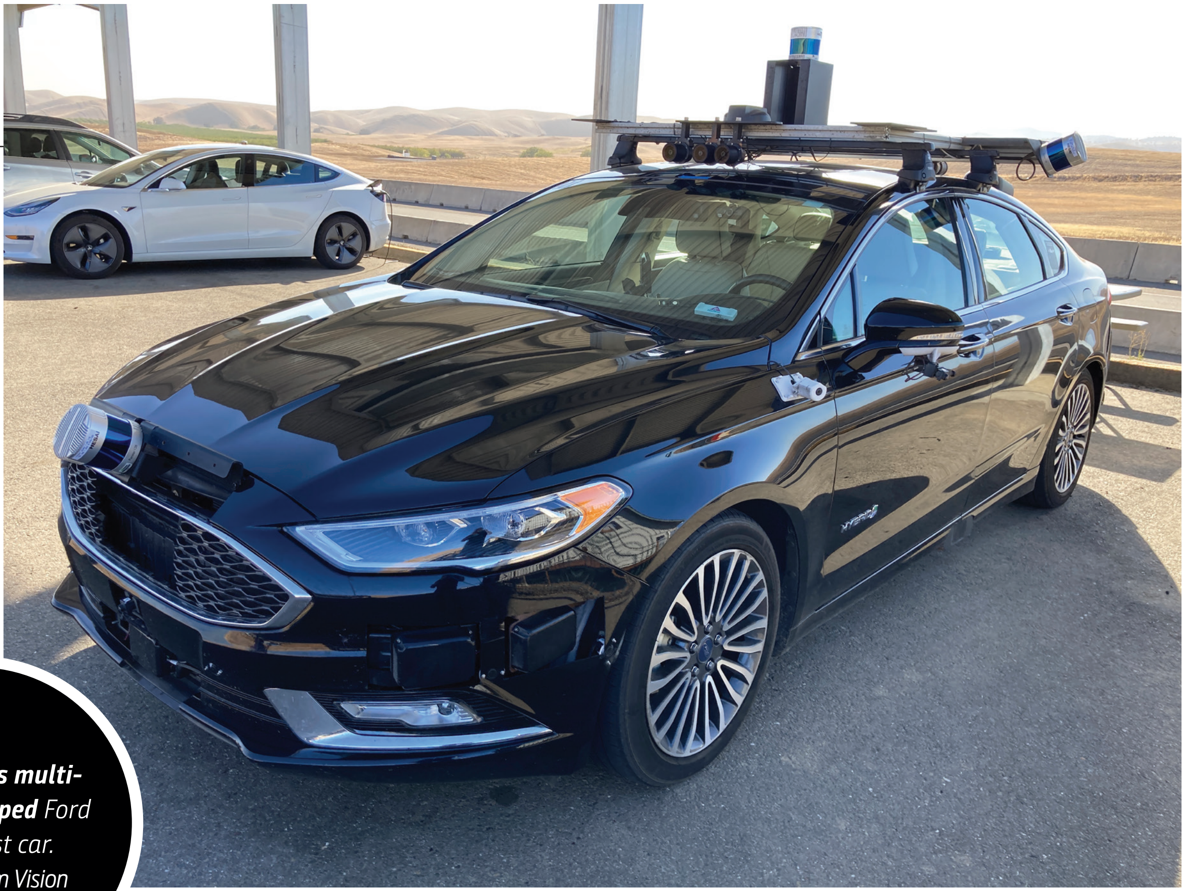
We tested three aspects of the Tangram Vision SDK at SRC: sensor runtime, multi-modal sensor synchronization, and LiDAR streaming.

Perhaps it was apt that we powered our RealSense with a Lucas alternator, as the RealSense series has gained a Lucas-like reputation for reliability among its many users. RealSense sensors can shut down unexpectedly, and can prove difficult to reboot quickly after a shutdown. The Tangram Vision runtime module is designed to solve these stability issues by integrating RealSense libraries into Rust, a memory-safe programming language that is becoming increasingly popular in robotics. By leveraging many of the safety features of Rust, the Tangram Vision runtime was able to stream the USB-equipped D435i consistently and reliably throughout the event. This was tested with an instant boot prior to our lapping session, and thirty minutes of continuous, fault-free data collection during our high-speed mapping laps of Thunderhill's 2.5 mile West track.



The sensor array mounted *on top of the classic Mini.*

📷 | *Tangram Vision*



NVIDIA R&D's multi-sensor equipped *Ford Fusion test car.*
📷 | *Tangram Vision*

Our Velodyne LiDAR testing was simpler; we'll be releasing support for LiDAR runtime, calibration, and spatial registration in the Tangram Vision SDK in the near term, and SRC allowed us an opportunity to test our LiDAR pipeline. Unfortunately, one of our Velodyne Puck units failed before we began testing, so we were only able to capture data from a single LiDAR unit during the event.

For the Velodyne Puck and Intel RealSense D435i sensors that did work during the SRC weekend, we were able to capture simultaneous datasets to test real-time sensor synchronization across two different sensing modalities from two different sensor manufacturers (these synchronized data sets, as well as other team's data sets, will be released on the SRC website in the next few weeks).

We'd be remiss if we did not mention the harsh environment under which our systems and other teams' systems were tested. With a noontime high temperature of 86°F and no clouds in the sky, cars, sensors, and drivers alike were heat-soaked and saturated in full-spectrum sunlight. Thunderhill Raceway's West track was opened in 2014, with a challenging layout full of decreasing radius corners, elevation changes, and off-camber chicanes. Collectively, these twists and turns ensure that even the most stable sensor will experience physical forces outside of what would be encountered on a typical city street or inter-urban highway.

Other teams at SRC

SRC attracts a diverse set of teams that bring different kinds of vehicles with different levels of autonomy. Along with Tangram Vision, other teams that participated in SRC this year included:

- PointOne Navigation: Provides spatial localization for autonomous and ADAS-enabled cars. PointOne Navigation not only completed this year's fastest full autonomous lap with their self-driving Lexus, but also completed a full autonomous lap … in reverse.
- Qibus: Vehicle tele-operation on demand
- Faction: Lightweight, driverless vehicle fleets for delivery and transportation. Faction uses ArciMoto three-wheeled EVs.
- AEye: High-performance, adaptive LiDAR sensors.
- NVIDIA: NVIDIA's R&D team tested a Ford Fusion outfitted with multiple LiDARs, cameras, radars, and other sensors.
- Monarch Tractor: Compact, autonomous, electric tractors.
- Boltu Robotics: Autonomous delivery robots. Boltu brought an autonomous Prius to this year's event.

As it did this year after its 2020 Covid-19 hiatus, SRC will return to Thunderhill in 2022 for another weekend of autonomous excitement. Tangram Vision will be back with our Mini Cooper with added evolution in our sensor package. That said, we're still trying to figure out how to automate a manual gear shift. Got any ideas for us? Whether or not you can help us figure that one out, we highly recommend you sign up to participate or spectate at next year's event. **RR**

Robot uses vision, RF sensing to grasp hidden objects

The RFusion prototype relies on RFID tags that can be stuck to an item and reflect signals sent by an antenna. *Because RF signals can travel through most surfaces, RFusion is able to locate a tagged item within a pile.*

The Robot Report Staff

A busy commuter is ready to walk out the door, only to realize they've misplaced their keys and must search through piles of stuff to find them. Rapidly sifting through clutter, they wish they could figure out which pile was hiding the keys.

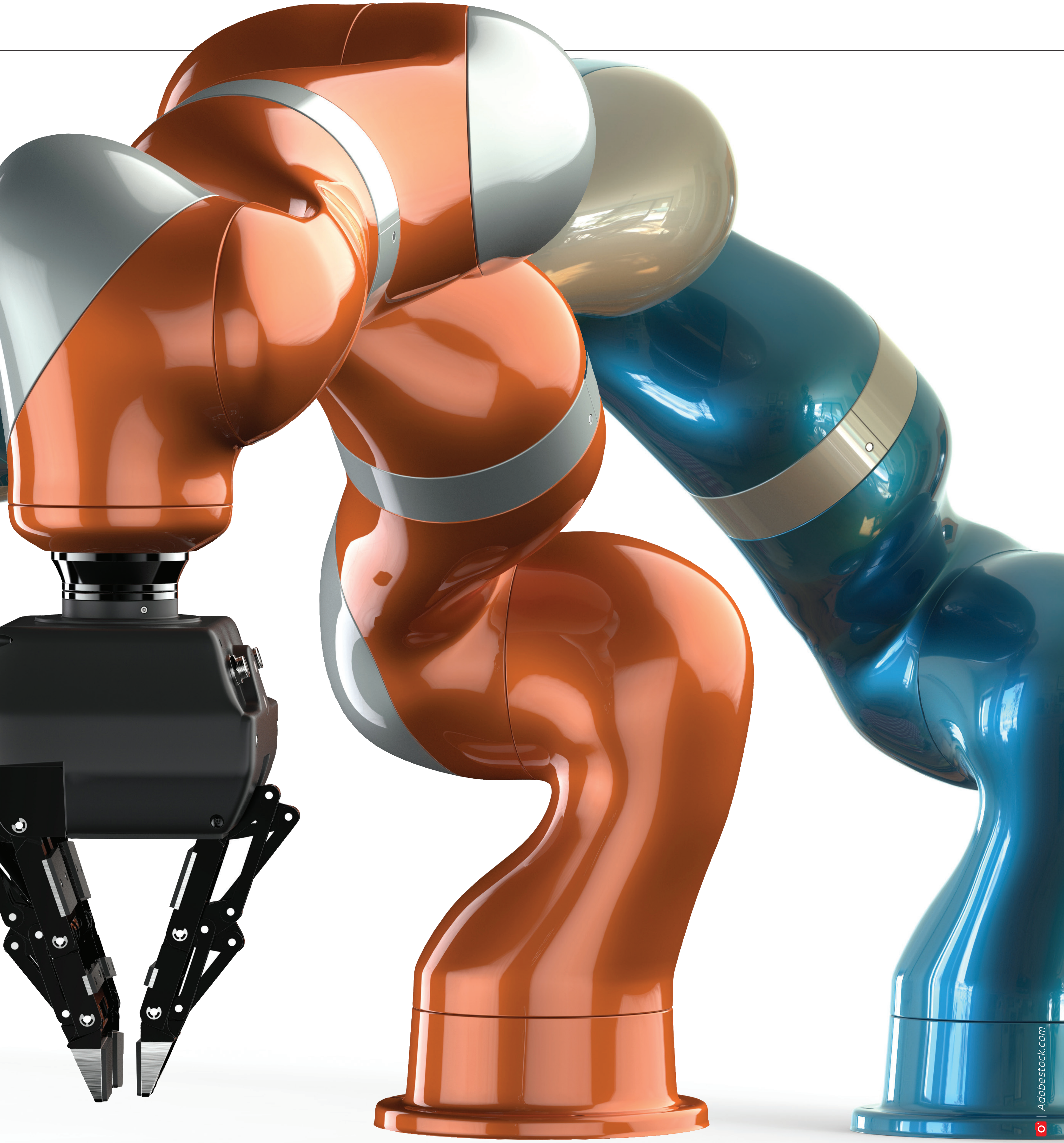
Researchers at MIT have created a robotic system that can do just that. The system, RFusion, is a robotic arm with a camera and radio frequency (RF) antenna attached to its gripper. It fuses signals from the antenna with visual input from the camera to locate and retrieve an item, even if the item is buried under a pile and completely out of view.

The RFusion prototype the researchers developed relies on RFID tags, which are cheap, battery-less tags that can be stuck to an item and reflect signals sent by an antenna. Because RF signals can travel through most surfaces (like the mound of dirty laundry that may be obscuring the keys), RFusion is able to locate a tagged item within a pile.

Using machine learning, the cobot arm from Universal Robots automatically zeroes-in on the object's exact location, moves the items on top of it, grasps the object, and verifies that it picked up the right thing. The camera, antenna, robotic arm, and AI are fully integrated, so RFusion can work in any environment without requiring a special set up.

While finding lost keys is helpful, RFusion could have many broader applications in the future, like sorting through piles to fulfill orders in a warehouse, identifying and installing components in an auto manufacturing plant, or helping an elderly individual perform daily tasks in the home, though the current prototype isn't quite fast enough yet for these uses.

"This idea of being able to find items in a chaotic world is an open problem that we've been working on for a few years. Having robots that are able to search for things under a pile is a



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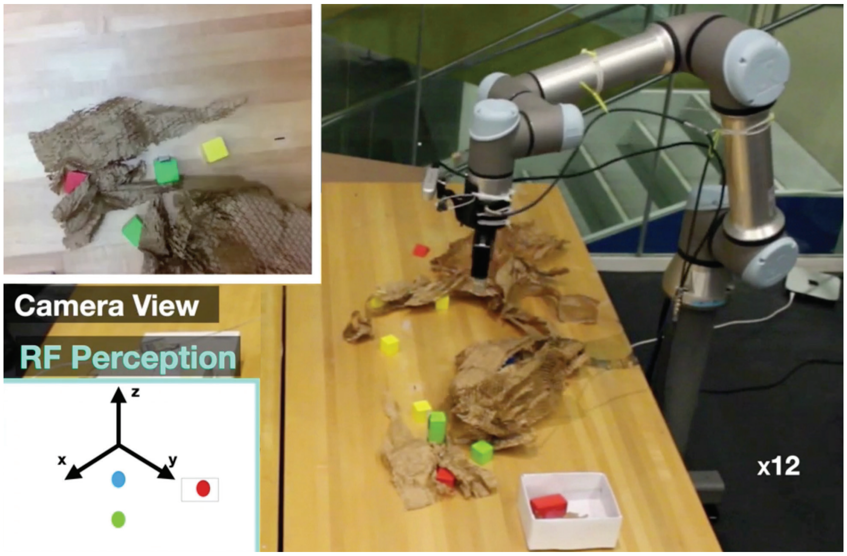

MIT researchers developed a robot that combines vision with radio frequency (RF) sensing to find and grasp objects, *even if they're hidden from view. The technology could aid fulfilment in e-commerce warehouses.* 📷 | *MIT*

growing need in industry today. Right now, you can think of this as a Roomba on steroids, but in the near term, this could have a lot of applications in manufacturing and warehouse environments," said senior author Fadel Adib, associate professor in the Department of Electrical Engineering and Computer Science and director of the Signal Kinetics group in the MIT Media Lab.

Co-authors include research assistant Tara Boroushaki, the lead author; electrical engineering and computer science graduate student Isaac Perper; research associate Mergen Nachin; and Alberto Rodriguez, the Class of 1957 Associate Professor in the Department of Mechanical Engineering.

Sending signals

RFusion begins searching for an object using its antenna, which bounces signals off the RFID tag (like sunlight being reflected off a mirror) to identify a spherical area in which the tag is located. It combines that sphere with the camera input, which narrows down the object's location. For instance, the item can't be located on an area of a table that is empty.

But once the robot has a general idea of where the item is, it would need to swing its arm widely around the room taking additional measurements to come up with the exact location, which is slow and inefficient.

The researchers used reinforcement learning to train a neural network that can optimize the robot's trajectory to the object. In reinforcement learning, the algorithm is trained through trial and error with a reward system.

"This is also how our brain learns. We get rewarded from our teachers, from our parents, from a computer game, etc. The same thing happens in reinforcement learning. We let the agent make mistakes or do something right and then we punish or reward the network. This is how the network learns something that is really hard for it to model," Boroushaki explains.

In the case of RFusion, the optimization algorithm was rewarded when it limited the number of moves it had to make to localize the item and the distance it had to travel to pick it up.

Once the system identifies the exact right spot, the neural network uses combined RF and visual information to predict how the robotic arm should grasp the object, including the angle of the hand and the width of the gripper, and whether it must remove other items first. It also scans the item's tag one last time to make sure it picked up the right object.

Cutting through clutter

The researchers tested RFusion in several different environments. They buried a keychain in a box full of clutter and hid a remote control under a pile of items on a couch.

But if they fed all the camera data and RF measurements to the reinforcement learning algorithm, it would have overwhelmed the system. So, drawing on the method a GPS uses to consolidate data from satellites, they summarized the RF measurements and limited the visual data to the area right in front of the robot.

Their approach worked well — RFusion had a 96 percent success rate when retrieving objects that were fully hidden under a pile.

"Sometimes, if you only rely on RF measurements, there is going to be an outlier, and if you rely only on vision, there is sometimes going to be a mistake from the camera. But if you combine them, they are going to correct each other. That is what made the system so robust," Boroushaki says.

In the future, the researchers hope to increase the speed of the system so it can move smoothly, rather than stopping periodically to take measurements. This would enable RFusion to be deployed in a fast-paced manufacturing or warehouse setting.

Beyond its potential industrial uses, a system like this could even be incorporated into future smart homes to assist people with any number of household tasks, Boroushaki says.

"Every year, billions of RFID tags are used to identify objects in today's complex supply chains, including clothing and lots of other consumer goods. The RFusion approach points the way to autonomous robots that can dig through a pile of mixed items and sort them out using the data stored in the RFID tags, much more efficiently than having to inspect each item individually, especially when the items look similar to a computer vision system," says Matthew S. Reynolds, CoMotion Presidential Innovation Fellow and associate professor of electrical and computer engineering at the University of Washington, who was not involved in the research. "The RFusion approach is a great step forward for robotics operating in complex supply chains where identifying and 'picking' the right item quickly and accurately is the key to getting orders fulfilled on time and keeping demanding customers happy." **RR**

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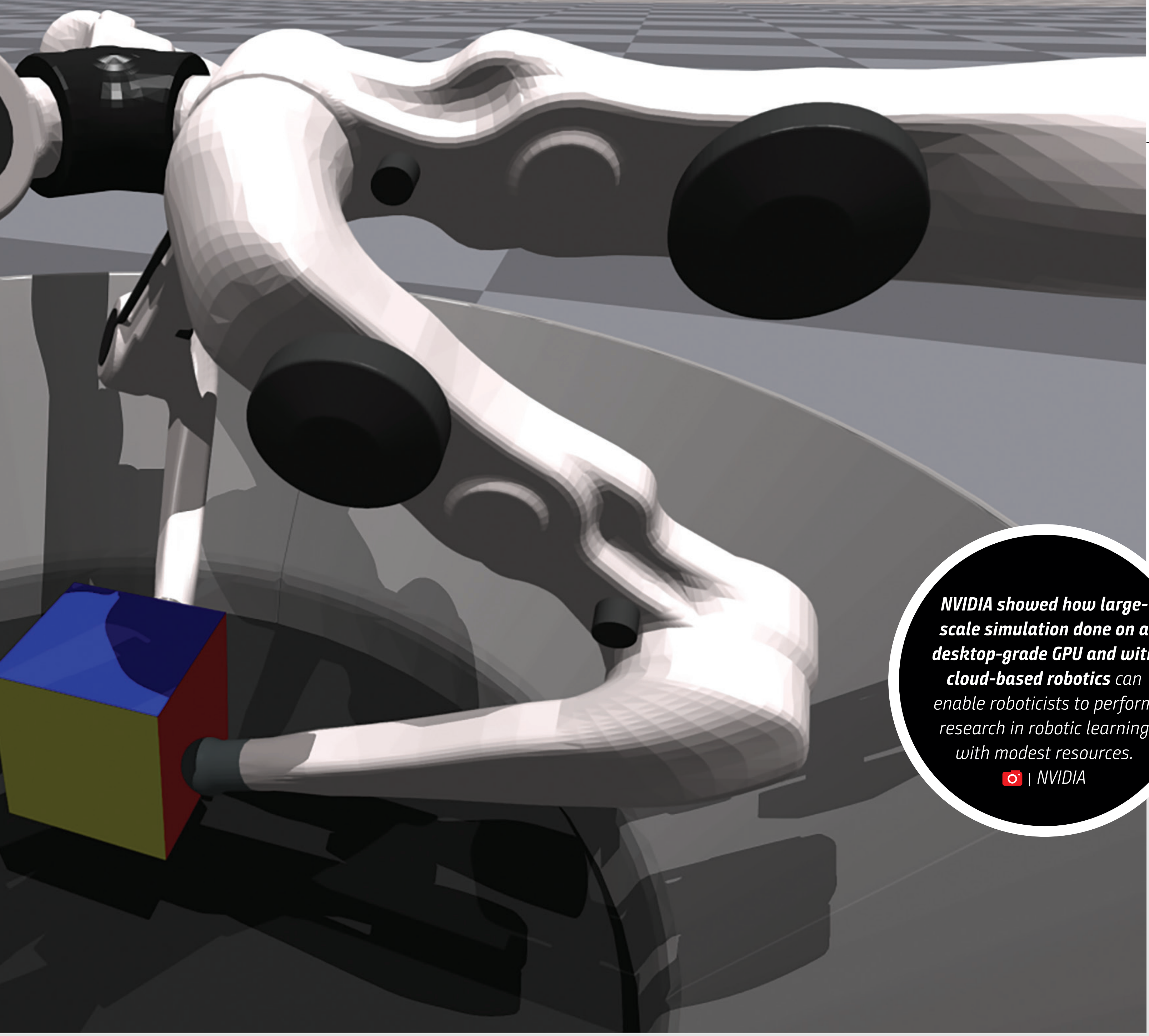
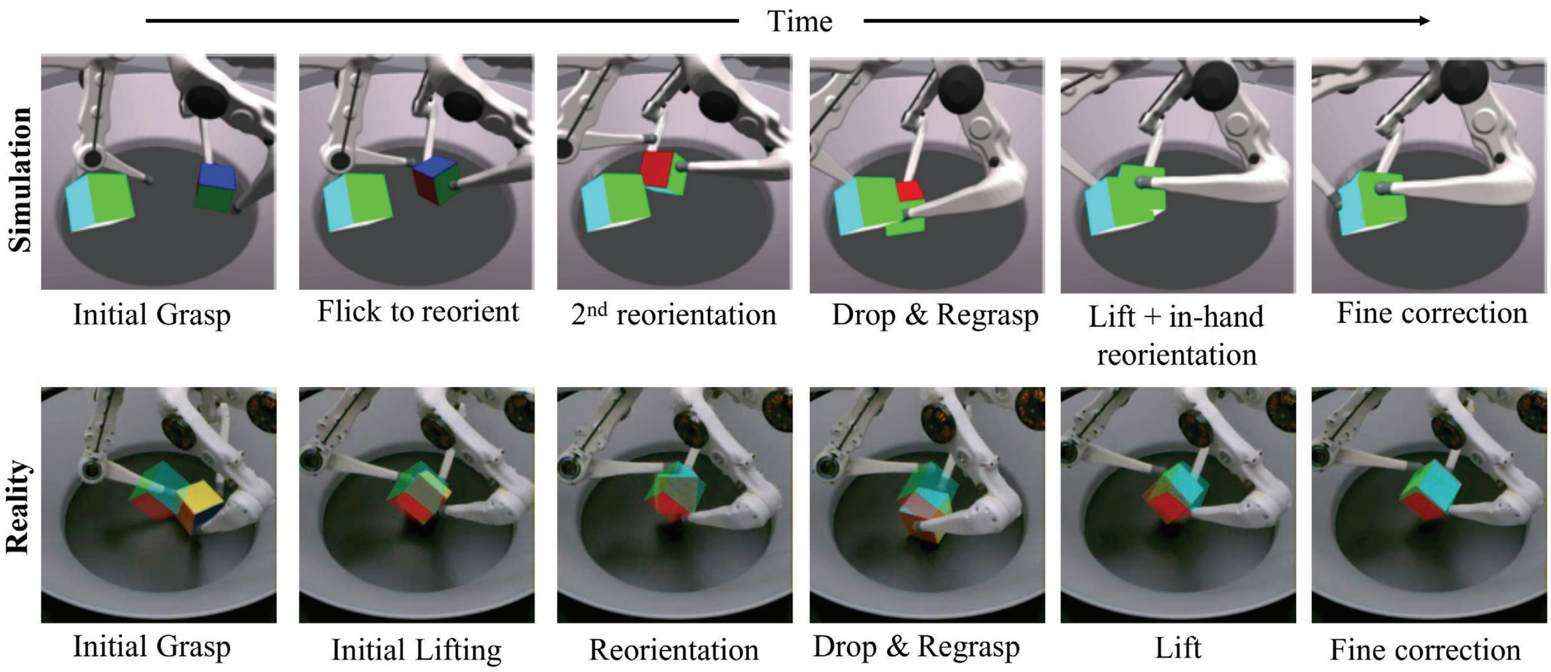


NVIDIA showed how large-scale simulation done on a desktop-grade GPU and with cloud-based robotics *can enable roboticists to perform research in robotic learning with modest resources.*
📷 | *NVIDIA*

Despite the lack of physical access to a robot, *researchers produced a robust and working policy to solve the 6DoF reposing task by combining several techniques.*

Dexterous, multifinger object manipulation has been one of the long-standing challenges in control and learning for robot manipulation. While challenges in high-dimensional control for locomotion as well as image-based object manipulation with simplified grippers have made remarkable progress in the last five years, multifinger dexterous manipulation remains a high-impact yet hard-to-crack problem. This challenge is due to a combination of issues:

- High-dimensional coordinated control
- Inefficient simulation platforms
- Uncertainty in observations and control in real-robot operation
- Lack of robust and cost-effective hardware platforms



A comparison of how the system grasped a cube in simulation (top) *and in the real world (bottom).*

| NVIDIA

These challenges, coupled with lack of availability of large-scale compute and robotic hardware, has limited diversity among the teams attempting to address these problems.

Our goal in this effort is to present a path for democratization of robot learning and a viable solution through large-scale simulation and robotics-as-a-service. We focus on six degrees of freedom (6DoF) object manipulation by using a dexterous multifinger manipulator as a case study. We show how large-scale simulation done on a desktop-grade GPU and with cloud-based robotics can enable roboticists to perform research in robotic learning with modest resources.

While several efforts around in-hand manipulation have attempted to build robust systems, one of the most impressive demonstrations came a few years ago from a team at OpenAI that built a system termed Dactyl. It was an impressive feat of engineering to achieve multiobject in-hand reposing with a shadow hand.

However, it was remarkable not only for the final performance but also in the amount of compute and engineering effort to build this demo. As per public estimates, it used 13,000 years of computing and the hardware itself was costly and yet required repeated interventions. The immense resource requirement effectively prevented others from reproducing this result and as a result building on it.

In this article, we show that our system's effort is a path to address this resource inequality. A similar result can now be achieved in under a day using a single desktop-grade GPU and CPU.

Complexity of standard pose representations in the context of reinforcement learning

During the initial experimentation, we followed previous works in providing our policy with observations based on a 3D Cartesian position plus a four-dimensional quaternion representation of pose to specify the current and target position of the cube. We also fixed the reward based on the L2 norm (position) and angular difference (orientation) between the desired and current pose of the cube.

We found this approach to produce unstable reward curves, which were good at optimizing the position portion of the reward, even after adjusting relative weightings.

Prior work has shown the benefits of alternate representations of spatial rotation when using neural networks. Furthermore, it has been shown that mixing losses this way can lead to collapsing towards only optimizing a single objective.

Inspired by this, we searched for a representation of pose in SO(3) for our 6DoF reposing problem. This would also naturally trade off position and rotation rewards in a way suited to optimization through reinforcement learning.

Closing Sim2Real gap with remote robots

The problem of access to physical robots was exacerbated by the COVID-19 pandemic. Those previously fortunate enough to have access to robots in their research groups found that the number of people with physical access to the robots was greatly decreased. Those that relied on other institutions to provide the

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hardware were often alienated completely due to physical distancing restrictions.

Our work demonstrated the feasibility of a robotics-as-a-service (RaaS) approach in tandem with robot learning. A small team of people trained to maintain the robot and a separate team of researchers could upload a trained policy and remotely collect data for post-processing.

While our team of researchers was primarily based in North America, the physical robot was in Europe. For the duration of the project, our development team was never physically in the same room as the robots on which we were working. Remote access meant that we could not vary the task at hand to make it easier. It also limited the kinds of iteration and experiments that we could do. For example, reasoned system identification was not possible, as our policy ran on a randomly chosen robot in the entire farm.

Despite the lack of physical access, we found that we were able to produce a robust and working policy to solve the 6DoF reposing task through a combination of several techniques:

- Realistic GPU-accelerated simulation
- Model-free RL
- Domain randomization
- Task-appropriate representation of pose

Method overview

Our system trains using the IsaacGym simulator on 16,384 environments in parallel on a single NVIDIA V100 or NVIDIA RTX 3090 GPU. Inference is then conducted remotely on a TriFinger robot located across the Atlantic in Germany using the uploaded actor weights. The infrastructure on which we perform Sim2Real transfer is provided courtesy of the organizers of the Real Robot Challenge.

Collect and process training examples

Using the IsaacGym simulator, we gathered high-throughput experience (~100K samples/sec on an NVIDIA RTX 3090). The sample's object pose and goal pose are to eight key points of the object's shape. Domain randomizations were applied to the observations and environment parameters to simulate variations in the proprioceptive sensors of the real robots and cameras. These observations, along with some privileged state information from the simulator, were then used to train our policy.

Train the policy

Our policy was trained to maximize a custom reward using the proximal policy optimization (PPO) algorithm. Our reward incentivized the policy to balance the distance of the robot's fingers from the object, speed of movement, and distance from the object to a specified goal position. It solved the task efficiently, despite being a general formulation applicable broadly across in-hand manipulation applications. The policy out put the torques for each of the robot's motors, which were then passed back into the simulation environment.

Transfer the policy to a real robot and run inference

After we trained the policy, we uploaded it to the controller for the real robot. The cube was tracked on the system using three cameras. We combined proprioceptive information available from the system along with the converted keypoints representation to provide input to the policy. We repeated the camera-based cube-pose observations for subsequent rounds of policy evaluation to enable the policy to take advantage of the higher-frequency proprioceptive data available to the robot. The data collected from the system was then used to determine the success rate of the policy.

The tracking system on the robot currently only supports cubes. However, this could be extended in future to arbitrary objects.

Results

The key points representation of pose greatly improves success rate and convergence.

We demonstrated that the policies that used our keypoint representation, in either the observation provided to the policy or in reward calculation, achieved a higher success rate than using a position+quaternion representation. The highest performance came from the policies that used the alternate representation for both elements.

We performed experiments to see how the use of keypoints impacted the speed and convergence level of our trained policies. As can be seen, using keypoints as part of the reward considerably sped up training, improved the eventual success rate, and reduced variance between trained policies. The magnitude of the difference was surprising, given the simplicity and generality of using keypoints as part of the reward.

The trained policies can be deployed straight from the simulator to remote real robots. There's also an emergent behavior we've termed "dropping and regrasping." In this maneuver, the robot learns to drop a cube when it is close to the correct position, regrasp it, and pick it back up. This enables the robot to get a stable grasp on the cube in the right position, which leads to more successful attempts. It's worth noting that this video is in real time and not sped up in any way.

The robot also learns to use the motion of the cube to the correct location in the arena as an opportunity to rotate it on the ground simultaneously. This helps achieve the correct grasp in challenging target locations far from the center of the fingers' workspace.

Our policy is also robust towards dropping. The robot can recover from a cube falling out of the hand and retrieve it from the ground.

Robustness to physics and object variations

Our policy was robust to variations in environment parameters in simulation. For example, it gracefully handled scaling up and down of the cube by ranges far exceeding randomization.

Surprisingly, we found that our policies were able to generalize 0-shot to other objects, for example, a cuboid or a ball. Generalization in scale and object is taking place due to the policy's own robustness. We do not give it any shape information. The keypoints remain in the same place as they would on a cube.

Conclusion

Our method shows a viable path for robot learning through large-scale, GPU-based simulation. It is possible to train a policy using moderate levels of computational resources (desktop-level compute) and transfer it to a remote robot. These policies can be robust to a variety of changes in the environment and the object being manipulated. We hope our work can serve as a platform for researchers going forward. RR

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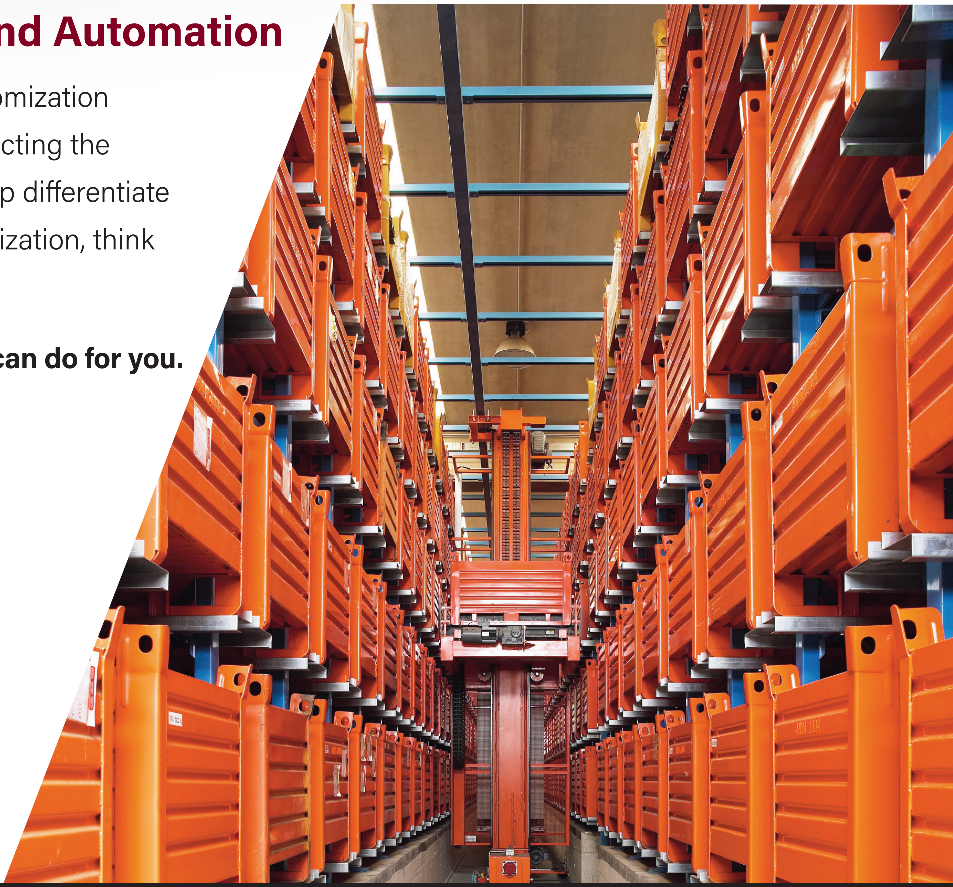

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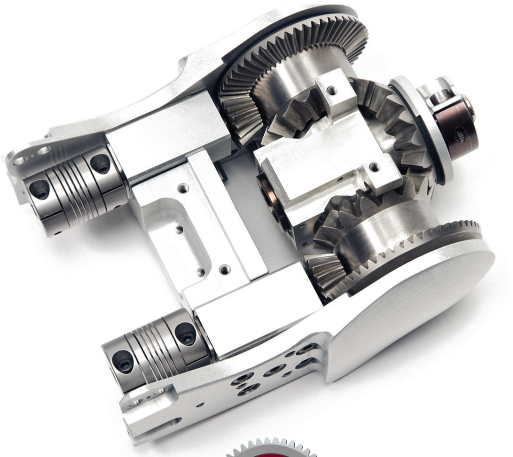

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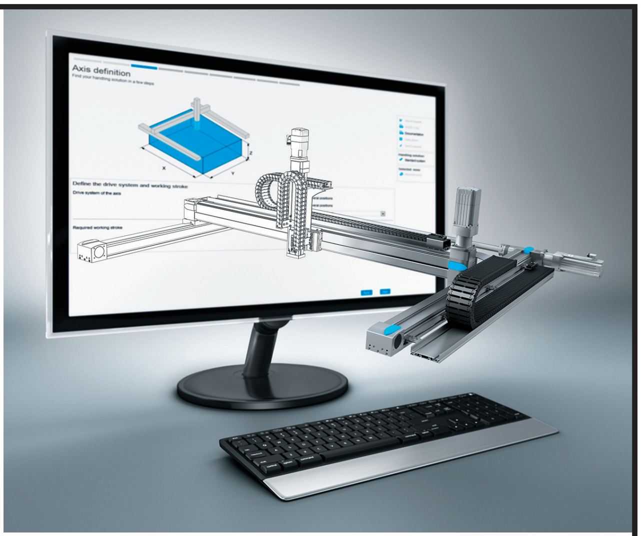

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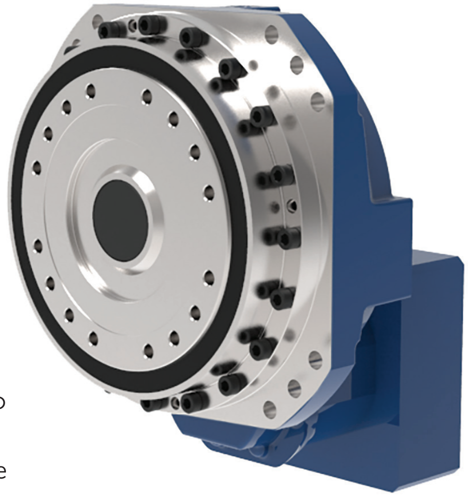

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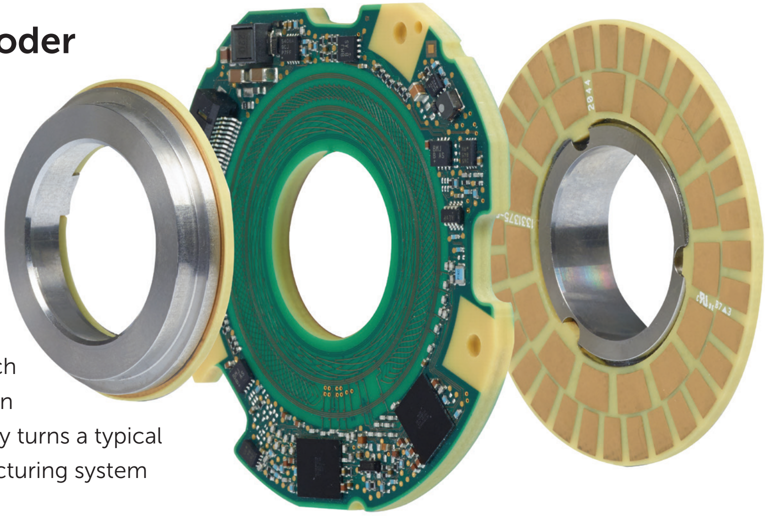

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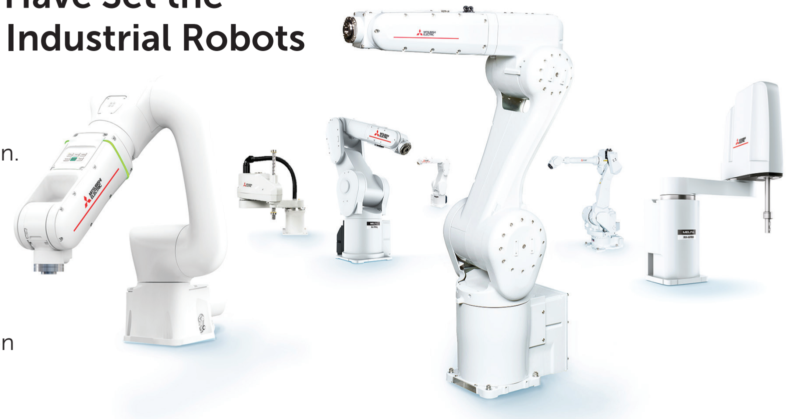

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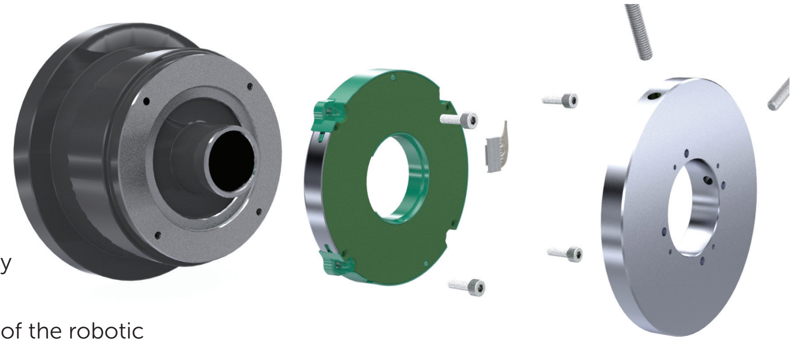

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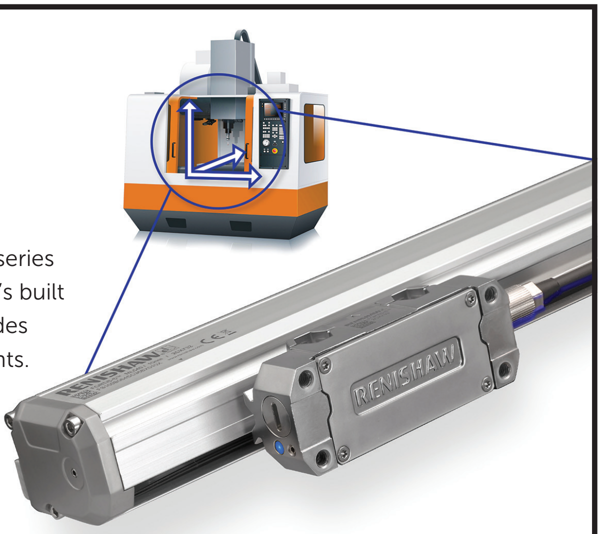

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-Ian Eldred, Principal Mechanical Engineer at Renishaw

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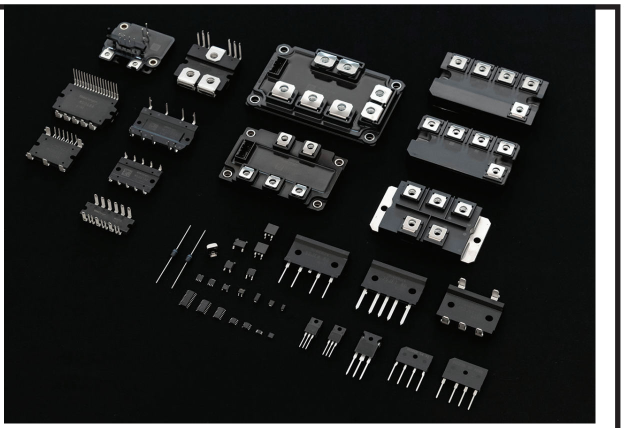

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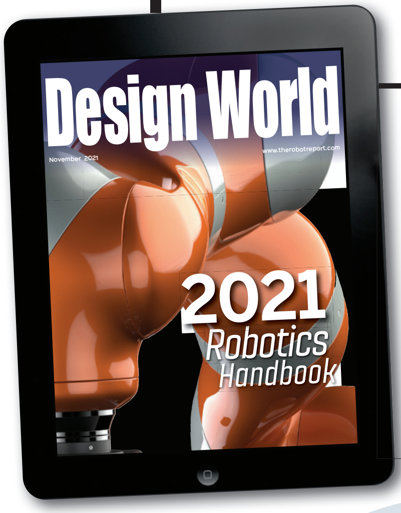

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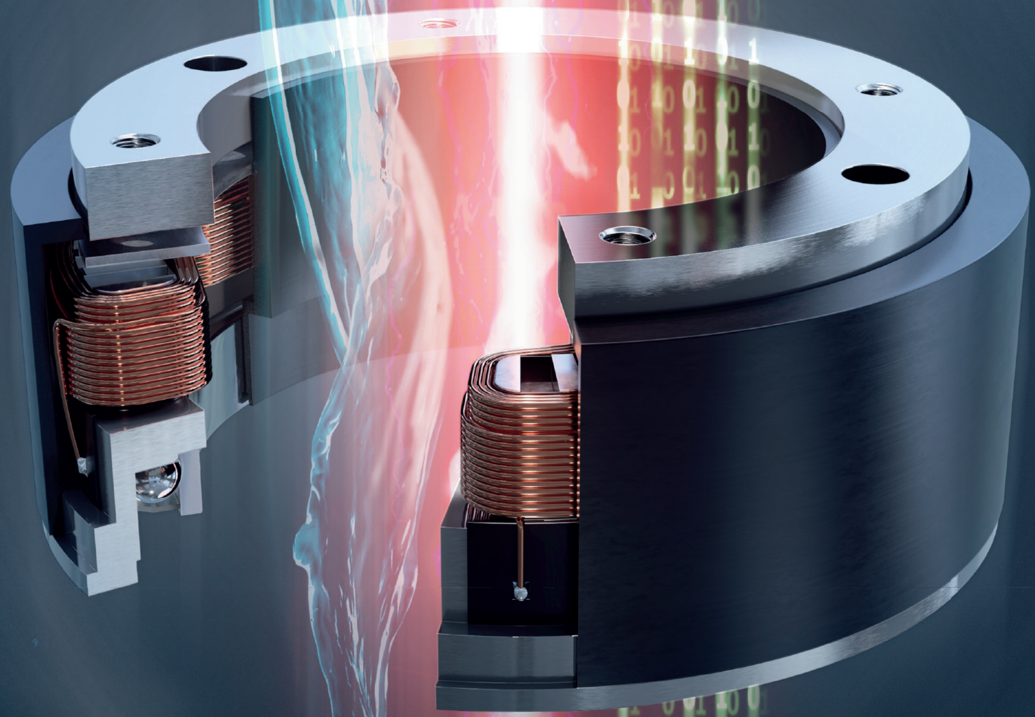
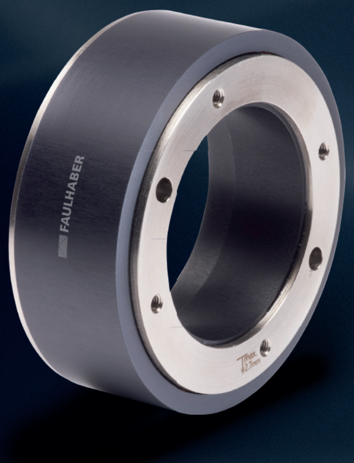
FAULHABER



FAULHABER Stepper Motors

Applications?
Step into the ring.



The new hollow shaft stepper motor DM 66200H series operates backlash-free and can be easily integrated into challenging applications, across diverse markets.

faulhaber.com/ringstepper/en

WE CREATE MOTION

FUTEK
ADVANCED SENSOR TECHNOLOGY, INC.

Conceptual rendering of the multi-jointed robotic arm of a surgical system.

Giving robots a sense of touch

FUTEK's miniaturized sensor technology allows surgeons to perform as if they had virtual fingertips. The sensors' precise measurement and feedback allow the machine to emulate the dexterity and haptics of human hands.

go.futek.com/medtech

QTA143

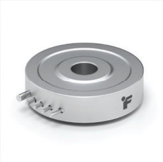
❶ Micro Reaction Torque Sensor

Dimensions: 14 mm × 10 mm × 26 mm
Provides closed-loop feedback on torque measurement.

LSB205

❷ Miniature S-Beam Jr. Load Cell

Dimensions: 19 mm × 18 mm × 6.6 mm
Provides critical force feedback.



QLA401

❸ Load Cell Built for Autoclave

Dimensions: Ø 14 mm × 3.28 mm
Designed to withstand the autoclave sterilization process.

QLA414

❹ Nano Force Sensor

Dimensions: 4mm × 5mm
Enables direct measurement that eliminates any drift in the output.

ANSI Z540-1
ISO 17025
ISO 9001
ISO 13485
U.S. Manufacturer